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## A New Geographic Locality and Three New Host Records for *Neobenedenia melleni* (MacCallum) (Monogenea: Capsalidae)

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# A NEW GEOGRAPHIC LOCALITY AND THREE NEW HOST RECORDS FOR *NEOBENEDENIA MELLENI* (MACCALLUM) (MONOGENEA: CAPSALIDAE)

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*ABSTRACT* A new geographic locality record and three new host records for *Neobenedenia melleni* (MacCallum, 1927) (Monogenea: Capsalidae) are provided. Specimens of *N. melleni* were collected from the skin of three Florida pompano, *Trachinotus carolinus* (Linnaeus, 1766) (Carangidae), caught in the northern Gulf of Mexico off Horn Island, Mississippi; from the skin of a bluering angelfish, *Pomacanthus annularis* (Bloch, 1787) (Pomacanthidae), in the Shark Reef Aquarium at Mandalay Bay, Las Vegas, Nevada; from the skin of a rock greenling, *Hexagrammos lagocephalus* (Pallas, 1810) (Hexagrammidae), in the Alaska SeaLife Center, Seward, Alaska; and from the skin of two blue-barred ribbon gobies, *Oxymetopon cyanoctenosum* Klausewitz and Condé, 1981 (Microdesmidae), in a tropical fish clearinghouse in Hayward, California. This is the first published record of the parasite from a microdesmid or wild carangid. Prior to this report, no specimen of *N. melleni* had been reported from a wild-caught fish in the Gulf of Mexico. The presence of *N. melleni* in the Gulf of Mexico is particularly noteworthy because this monogenean is a known pathogen of cultured fishes in netpens and recirculating seawater systems.

## INTRODUCTION

*Neobenedenia melleni* (MacCallum, 1927) (Monogenea: Capsalidae) is a serious pathogen of confined teleosts because it exhibits a direct life cycle and a low degree of host specificity as well as an apparent low degree of site specificity. It infects the eyes, fins, gill cavity, nasal cavity, and skin of primarily shallow-water or reef-dwelling teleosts ranging from tropical to temperate marine and brackish waters (Bullard et al. 2000); however, the site preference and microhabitat of *N. melleni* have not been studied in great detail (Whittington and Horton 1996). This parasite is unique among other monogeneans in that it has a broad host range and wide geographic distribution, infecting 26 fishes in 18 genera, 14 families, and three orders in the Caribbean Sea and Eastern Pacific Ocean as well as over 80 teleost species in public aquaria and aquaculture systems (for specific hosts see Whittington and Horton 1996, Bullard et al. 2000). Published wild, free-ranging, host records for *N. melleni* are relatively scarce, probably because specimens are overlooked during routine examinations of fishes: specimens of *N. melleni* are thin, flat, and opaque-white or nearly transparent, making them difficult to see and collect if the host's external surface is not examined critically and with adequate lighting. Furthermore, infected wild hosts are not obvi-

ous because they typically harbor few worms and lack a gross lesion. There is no report of a disease and no detailed information regarding a lesion associated with an infection of *N. melleni* in a wild host. Conversely, fishes in netpens, aquaria, and other recirculating seawater systems routinely develop intense infections of *N. melleni* marked by bloody lesions, body discoloration, emaciation, erratic behavior (i.e., rubbing against objects and flashing), and mortality (Jahn and Kuhn 1932, Nigrelli and Breder 1934, Robinson et al. 1992, Ogawa et al. 1995). Mueller et al. (1994) stated that infections of *N. melleni* may constrain the tropical finfish mariculture industry until cost effective and environmentally sound treatments are discovered and implemented.

## MATERIALS AND METHODS

Florida pompano were caught by hook and line, pithed, and placed in a cooler with a small portion of ice prior to necropsy. Infected aquarium-held fishes were pithed and immediately necropsied or fixed whole in 10% neutral buffered formalin (n.b.f.) and necropsied at a later date. All worms were fixed directly in 10% n.b.f. or 70% ethanol (EtOH) without coverslip pressure or heat. Whole mounts of worms were stained in Van Cleave's hematoxylin with several additional drops of Ehrlich's hematoxylin, made basic at 70% EtOH with

lithium carbonate and butyl-amine, dehydrated, cleared in clove oil, and mounted in Canada balsam. Worms were identified using the original description of *N. melleni* (as *Epibdella melleni* MacCallum, 1927) and the redescription of *N. melleni* and key to species of *Neobenedenia* by Whittington and Horton (1996). The primary features that identified our specimens as belonging within *Neobenedenia* Yamaguti, 1963 were 1) accessory gland reservoir inside penis sac, 2) vagina absent, and 3) general orientation and path of ducts associated with the male and female reproductive tracts. Specific features were consistent with MacCallum (1927) and Whittington and Horton (1996). A specimen of *N. melleni* from the Florida pompano, *Trachinotus carolinus* (Linnaeus, 1766) (Carangidae), was deposited in the United States National Parasite Collection (USNPC) at Beltsville, Maryland, (USNPC No. 92528), and a specimen each from the bluering angelfish, *Pomacanthus annularis* (Bloch, 1787) (Pomacanthidae), the rock greenling, *Hexagrammos lagocephalus* (Pallas, 1810) (Hexagrammidae), and the blue-barred ribbon goby, *Oxymetopon cyanoctenosum* (Klausewitz and Condé, 1981) (Microdesmidae), was deposited there (USNPC Nos. 92529, 92530, 92531, respectively) and in the helminth collections of the H. W. Manter Laboratory (HWML) of the University of Nebraska State Museum at Lincoln, Nebraska, (HWML Nos. 16972, 16973, 16974, respectively). Common names of hosts follow those recommended by FishBase (see http://www.fishbase.org).

## RESULTS AND DISCUSSION

Information on the natural host range and geographic distribution of *N. melleni* could help aquaculture managers or aquarists prevent or control disease associated with infection by *N. melleni*. For example, if the proposed culture facility is sited within the geographic range of *N. melleni* and the fish species selected for culture is highly susceptible to infection by *N. melleni*, selection of another culture site or an alternate, possibly refractory fish species could reduce the risk of an epizootic. Regarding prophylaxis and treatment in aquaria, recognizing limits to the host range of *N. melleni* could allow aquarists to distinguish "low-risk" hosts, those that are refractive to infections, e.g., sharks, rays, and chimaeras (Chondrichthyes), from "high-risk" hosts, those that can serve as foci for captive infections, e.g., the Atlantic spadefish, *Chaetodipterus faber* (Broussonet, 1782) (Ephippidae), or some angelfishes (Pomacanthidae). Based on this information, low-risk

hosts may be spared from exposure to potentially stressful anthelminthic chemicals, and high-risk hosts can either be isolated and treated aggressively or excluded altogether from large-volume, species-diverse exhibits. Furthermore, quarantine protocols based on such information may reduce treatment costs, especially if infected fishes reside in voluminous exhibit tanks. Herein, we report specimens of *N. melleni* from a new geographic locality and from three new hosts.

Regarding our new locality record, three adult specimens of *N. melleni* were collected from the skin of three of 31 (10%) adult Florida pompano (each 34–41 cm in total length) caught in July and August 2000 in the northern Gulf of Mexico off Horn Island, Mississippi. This is the first published record of *N. melleni* from a wild carangid. A gross lesion was not evident near the attachment site of *N. melleni*, and infected Florida pompano were grossly indistinguishable from those that were uninfected. *Neobenedenia melleni* was reported previously from Florida pompano both in the New York Aquarium (Jahn and Kuhn 1932, Nigrelli and Breder 1934, Nigrelli 1935, 1937) and in recirculating seawater tanks in Florida (Mueller et al. 1994). However, this is the first published record or confirmed report of *N. melleni* from a wild-caught fish in the Gulf of Mexico. Another report suggests that additional wild hosts reside in the Gulf of Mexico: Bullard et al. (2000) suspected red grouper, *Epinephelus morio* (Valenciennes, 1828) (Serranidae), and red snapper, *Lutjanus campechanus* (Poey, 1860) (Lutjanidae). In addition, Jahn and Kuhn (1932) suspected that *N. melleni* colonized the New York Aquarium by infected fishes that originally were caught off the Florida Keys or off Nassau, Bahamas, indicating that perhaps the parasite has ranged in the Gulf since the 1930s and that it was probably not artificially introduced to that region by the aquarium trade or aquaculture activities. Regarding the wide geographic distribution of *N. melleni*, Bullard et al. (2000) suggested the possibility that infections of *N. melleni* were vectored by infected remoras (Echeneidae), e.g., the whitefin sharksucker, *Echeneis neucratoides* Zouiev, 1786. However, the results of the present study suggest that, more simply, widely distributed hosts, e.g., Florida pompano ranging from the Atlantic Ocean off Massachusetts to off Brazil (Manooch, 1984), may transmit infections of this relatively non-host specific monogenean to endemic fishes throughout its range.

The low prevalence (10%) and intensity (1) of *N. melleni* in wild Florida pompano suggest that host schooling behavior may not facilitate horizontal transfer of *N. melleni*. Intuitively, the distance an

oncomiracidium must swim or crawl to infect a new host is negatively correlated with the chance of it infecting that host. As demonstrated by intense, debilitating infections among fishes crowded in aquaria, schooling behavior would seemingly increase the rate of infection and yield relatively intense infections because susceptible hosts are near each other. Despite this, our extremely limited data from wild Florida pompano did not support this notion. Alternatively, and from an evolutionary perspective, if host schooling behavior facilitated horizontal dispersal of monogenean larvae, the presumably strong selective pressure toward infecting schooling fishes could be evidenced by a species-diverse fauna of monogeneans or perhaps a relatively high intensity of infection on those fishes. However, there are seemingly conflicting reports regarding the matter of species diversity. Poulin and Rohde (1997) found no evidence that schooling fishes were infected by a greater number of gill- and skin-dwelling monogenean species. Santos and Carbonel (2000) considered 49 families of fishes in the midwestern and southwestern Atlantic Ocean and reported that jacks (Carangidae), drums (Sciaenidae), and tunas (Scombridae), all families that include schooling members, hosted the greatest number of monogenean genera: 18, 15, and 12, respectively. Additional collections of specimens of *N. melleni* from free-ranging schooling fishes could shed light on this question.

This report of *N. melleni* from Florida pompano is relevant to aquaculturists in the Gulf of Mexico because, as previously stated, *N. melleni* is a relatively non-host specific pathogen of fishes in aquaculture. Florida pompano is a candidate for culture in netpens or high density recirculating systems primarily because it is presently one of the most valuable table fish in tropical United States waters (Craig, 2000). *Neobenedenia melleni* (as *Neobenedenia girellae* [Hargis, 1955] Yamaguti, 1963) caused mass mortalities of caged amberjacks, *Seriola* spp. (Carangidae), in the Western Pacific Ocean off Japan (Ogawa et al., 1995), and a similar disease could occur in potential Florida pompano culture systems in the northern Gulf of Mexico. To lessen the risk of a captive epizootic, we advocate periodic and critical parasitological examinations of the skin, gills, eyes, and fins of several individual hosts sampled from the captive stock.

Regarding our new host records, specimens of *N. melleni* were also collected from the skin of a rock greenling at the Alaska SeaLife Center, Seward, Alaska. Although a concurrent infection occurred among three kelp greenling (*Hexagrammos decagrammus* [Pallas,

1810]) in a separate tank, a whitespotted greenling (*Hexagrammos stelleri* Tilesius, 1810) and several lingcod (*Ophiodon elongatus* Girard, 1854 [Hexagrammidae]) in the same tank as the infected rock greenling did not show signs of infection. The infected rock greenling was caught in Jakolof Bay (59 28' N; 151 32' W), Alaska, but where this fish and the kelp greenlings initially acquired the infection of *N. melleni* is not known. Whittington and Horton (1996) reported specimens of *N. melleni* from the gills of kelp greenling off San Juan County, Washington, making it plausible that *N. melleni* infects a closely-related, congeneric host north of that locality. The presence of *N. melleni* on a wild greenling off Alaska requires verification; however, if either of these greenlings was infected prior to capture, the northeast Pacific Ocean off Alaska would constitute both a substantial latitudinal range extension and the northern-most geographic locality record for *N. melleni*.

Thirteen specimens of *N. melleni* were collected from the skin of an adult bluering angelfish maintained in a 530,000 L exhibit tank at the Shark Reef Aquarium at Mandalay Bay, Las Vegas, Nevada. The infected bluering angelfish was emaciated and listless and possessed faded body coloration. Angelfishes have been previously identified as hosts for *N. melleni*, and Nigrelli and Breder (1934) stated that angelfishes were foci for epidemics because of their high susceptibility to infection. Nigrelli and Breder (1934) also reported *N. melleni* from the french angelfish, *Pomacanthus paru* (Bloch, 1787) and the gray angelfish, *Pomacanthus arcuatus* (Linnaeus, 1758) in the New York Aquarium.

Forty specimens of *N. melleni* were collected from the skin of two blue-barred ribbon gobies in a fish clearinghouse located in Hayward, California. This is the first report of *N. melleni* from a wormfish (Microdesmidae). Both hosts were flashing, emaciated, exuding excessive amounts of mucous which covered the body, and showing bloody lesions on the lower body surface near the pectoral fins. One of the blue-barred ribbon gobies died, presumably as a result of the infection. Although this fish ranges in the tropical western Pacific Ocean, we do not know the exact geographic origin of these individuals or where they were originally infected by *N. melleni*.

DNA sequence analysis of specimens of *N. melleni* collected from different oceans or from different host species could show that distinct parasite populations or morphologically similar species exist. For this reason and in addition to whole-mounts being deposited in a museum that will loan specimens, we advocate placing

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specimens of *N. melleni* in both 95% molecular grade ethanol for eventual molecular analysis and 10% neutral buffered formalin for morphological studies using a light microscope.

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# Gulf and Caribbean Research

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New Host and Distribution Records for *Leidya bimini* Pearse, 1951 in the Gulf of Mexico, with Comments on Related Taxa and a Redescription of *Cardiocepon pteroides* Nobili, 1906 (Crustacea: Isopoda: Bopyridae: Ioninae)

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# NEW HOST AND DISTRIBUTION RECORDS FOR *LEIDYA BIMINI* PEARSE, 1951 IN THE GULF OF MEXICO, WITH COMMENTS ON RELATED TAXA AND A REDESCRIPTION OF *CARDIOCEPON PTEROIDES* NOBILI, 1906 (CRUSTACEA: ISOPODA: BOPYRIDAE: IONINAE)

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ABSTRACT Examination of grapsoid crabs, *Armases cinereum* (Bosc, 1802), in the Tampa Bay area revealed that 3.7% were infested with the bopyrid isopod *Leidya bimini* Pearse, 1951. These records represent a new host for the parasite and an extension of its range into the Gulf of Mexico. The relationships between the species of *Leidya* Cornalia and Panceri, 1861 and related genera have been difficult to ascertain, partly due to improper placement of some taxa within genera. The genera *Leidya*, *Megacepon* George, 1947, *Allokepon* Markham, 1982, and *Cardiocepon* Nobili, 1906 are discussed in terms of their species composition and phylogenetic relationships. Three species are placed in new combinations with genera: *Leidya sesarmae* Pearse, 1930 is tentatively placed in *Megacepon*, *Allokepon goetici* (Shiino, 1934) is transferred to *Megacepon*, and *Portunicepon tiariniae* Shiino, 1937 is transferred to *Allokepon*. The holotype of *Cardiocepon pteroides* Nobili, 1906 is redescribed and figured, and some errors in the original description are corrected.

## INTRODUCTION

A collection of 191 specimens of the grapsoid crab *Armases cinereum* (Bosc, 1802) was made in the Tampa Bay area by Brian Mahon in 1998 during a survey of semiterrestrial crabs (Grapsidae and Ocypodidae) and seven of these were found to be parasitized by bopyrid isopods. Examination of the parasites showed them to be conspecific with *Leidya bimini* Pearse, 1951, a species originally described from the Bahamas on the grapsoid crab *Pachygrapsus transversus* (Gibbes, 1850). This bopyrid has subsequently been reported from Miami, Key West, and Galeta Island, Panama, on *P. transversus*, and from Miami on the grapsoid *Armases ricordi* (H. Milne Edwards, 1853) (Markham 1972). The 1998 collection from Tampa Bay represents a range extension of this bopyrid species into the Gulf of Mexico, and the first record of its occurrence on *Armases cinereum*. Remarks are provided on the other known species of *Leidya* Cornalia and Panceri, 1861, as well as species in the closely related genera *Megacepon* George, 1947, *Allokepon* Markham, 1982 and *Cardiocepon* Nobili, 1906. The holotype of *C. pteroides* Nobili, 1906 is redescribed and figured, and some errors in the original description are corrected.

All measurements are given in millimeters; host size is given as carapace width; parasite size is given as total length from anterior margin of head to posterior margin of pleotelson. Three pairs of bopyrid specimens and one lone female are deposited with hosts as vouchers in the American Museum of Natural History (AMNH) and two pairs of specimens are in the collection of Brian Mahon. An additional pair of specimens was prepared for SEM but accidentally destroyed following examination. The holotype of *Cardiocepon pteroides* was borrowed from the Museo Civico di Storia Naturale "G. Doria," Genova, Italy (MCSN).

## RESULTS

### Family Bopyridae Rafinesque-Schmaltz, 1815
### Subfamily Ioninae H. Milne Edwards, 1840
### *Leidya* Cornalia and Panceri, 1861

*Leidya* Cornalia and Panceri 1861: 114.—Bourdon 1967: 115.—Bourdon and Bowman 1970: 422.—Bourdon and Stock 1979: 217.—Markham 1980: 628–629.—Bourdon 1981: 106–107.

**Included species.** *L. distorta* (Leidy, 1855) (type species by monotypy); *L. ucae* Pearse, 1930; *L. bimini* Pearse, 1951; *L. infelix* Markham, 2002.

**Host families and genera.** OCYPODIDAE: *Uca* (*L. distorta*: Bourdon and Bowman 1970, Roccatagliata and Torres Jordá 2002; *L. ucae*: Pearse 1930), *Ucides* (*L. distorta*: Lemos de Castro 1973); GRAPSIDAE: *Pachygrapsus* (*L. bimini*: Pearse 1951, Bourdon and Bowman 1970; *L. infelix*: Markham 2002; herein); *?Cyclograpsus* (*L. bimini*: Bourdon and Bowman 1970); *Armases* (*L. bimini*: Markham 1972; herein).

**Distribution.** New Jersey, USA to Río de la Plata, Argentina (*L. distorta*); Bermuda, Bahamas, Jamaica, Florida, USA (Atlantic and Gulf coasts) (*L. bimini*);

California, USA and Baja California, Mexico (*L. infelix*); China (*L. ucae*).

**Remarks.** *Leidya infelix* from the west coast of North America has recently been described and appears to be the sister species to the clade containing *L. distorta* and *L. bimini*. Two Asian species have also been placed in this genus: *L. sesarmae* Pearse, 1930, and *L. ucae* Pearse, 1930, but neither of those species was well-described, the types of both taxa were until recently considered lost (Markham 1982), and neither species has been reported subsequently. Based on the rather poor descriptions and illustrations of Pearse (1930) it appears that *Leidya ucae*, described from a male and female pair, is a genuine *Leidya*; this has been confirmed through examination of the recently rediscovered types in the Smithsonian Institution (Markham, personal communication). The female *L. ucae*, although immature, shows the characteristic form of the pleopods for the genus and, if the "mental plate" illustrated by Pearse (1930: plate 1, figure 2) is indeed the first oostegite, this species possesses the important character state of an elongate first oostegite. In contrast, *L. sesarmae* was described based solely on the male, but does not appear to belong to this genus; the extremely elongate and tapered lateral margins of the pleon and the swollen and pronounced pleopods are unlike other species of *Leidya*. The shape of the pleonites and development of the pleopods suggests that *L. sesarmae* may be congeneric with *Portunicepon goetici* Shiino, 1934, although that species belongs in *Megacepon* (see below). *Leidya sesarmae* is hereby removed from the genus *Leidya* and tentatively placed in the genus *Megacepon*, although its definitive generic placement remains unclear in the absence of female specimens and the missing holotype.

It is interesting that, of the four currently recognized species of *Leidya*, two are grapsoid parasites and two are ocypodid parasites with one of each occurring in the Atlantic and the Pacific. The original host-preferences of this genus are enigmatic, raising the question of whether the ancestor of *Leidya* was an ocypodid parasite, with infestation of grapsoids being the derived state, or vice versa? Unfortunately, the two closely related genera to *Leidya*, *Megacepon*, and *Cardiocepon* are parasites of grapsoids and gecarcinids, respectively, and this does not add any insight into the question of original *Leidya* host preference.

## *Leidya bimini* Pearse, 1951
### Figure 1

*Leidya bimini* Pearse 1951: 368–369, figures 77a–i.—Bourdon and Bowman 1970: 419 (full synonymy), figures 6a–c.—Markham 1972: 190–192, figure 1.—Markham, 1979: 524.—Markham 1980: 628–629.—Bourdon 1981: 106.—Markham 1988: 56 (list).—McDermott 1991: 71–95.

*Leidya distorta* Richardson, 1908: 23–26, figures 1–5 (not *Leidya distorta* sensu Leidy, 1855).

**Material.** USA, Florida, Hillsborough County, coll. B. Mahon.—Davis Island, March 1998, host and parasites not measured (in right branchial chamber of host) (Mahon Collection).—Manatee River, 2 August 1998, host male 9.6 mm, female (w/epicarid larvae) 5.3 mm, male absent (in right branchial chamber of host) (AMNH 18464).—SW Gandy Bridge, 17 July 1998, host male 9.5 mm, female 4.5 mm, male 2.3 mm (in left branchial chamber of host) (AMNH 18465).—NW Gandy Bridge, 11 October 1998, host female 9.5 mm, female 5.0 mm, male 2.5 mm (in right branchial chamber of host) (destroyed during SEM; host AMNH 18466).—NW Gandy Bridge, 11 October 1998, host and parasites not measured (in right branchial chamber of host) (Mahon Collection).—NE Courtney Campbell Causeway, 4 June 1998, host female 8.5 mm, female (w/epicarid larvae) 5.0 mm, male 1.9 mm (in left branchial chamber of host) (AMNH 18467).—NE Courtney Campbell Causeway, 4 June 1998, host male 8.7 mm, female 5.3 mm, male 2.3 mm (in right branchial chamber of host) (AMNH 18468).

**Remarks.** All of the specimens examined herein conform to published descriptions of *Leidya bimini* (Pearse 1951, Bourdon and Bowman 1970, Markham 1972) in all important characters such as the structure of the female pleopods (Figure 1A), elongate shape of the first oostegite of the female, number and placement of the dorsal thoracic bosses on the female, long filiform "uropods" of the male (Figure 1B), and strong medioventral tubercles on pleonites I-V of the male (Figure 1B). Note that the SEM of the "uropods" (Figure 1B) shows no distinct segmentation line at the junction with the pleotelson; these structures may in fact be only hyper-elongated distolateral lobes of the pleotelson. The validity of *Leidya bimini* was demonstrated by Bourdon and Bowman (1970), who convincingly separated it from its western Atlantic congener *L. distorta* (Leidy, 1855). The adult isopod infestation prevalence for the Tampa Bay *L. bimini* was 3.7% (7 of 191 specimens), at the low end of the 1.3–16.2% reported from *Pachygrapsus transversus* (Gibbes) in Bermuda
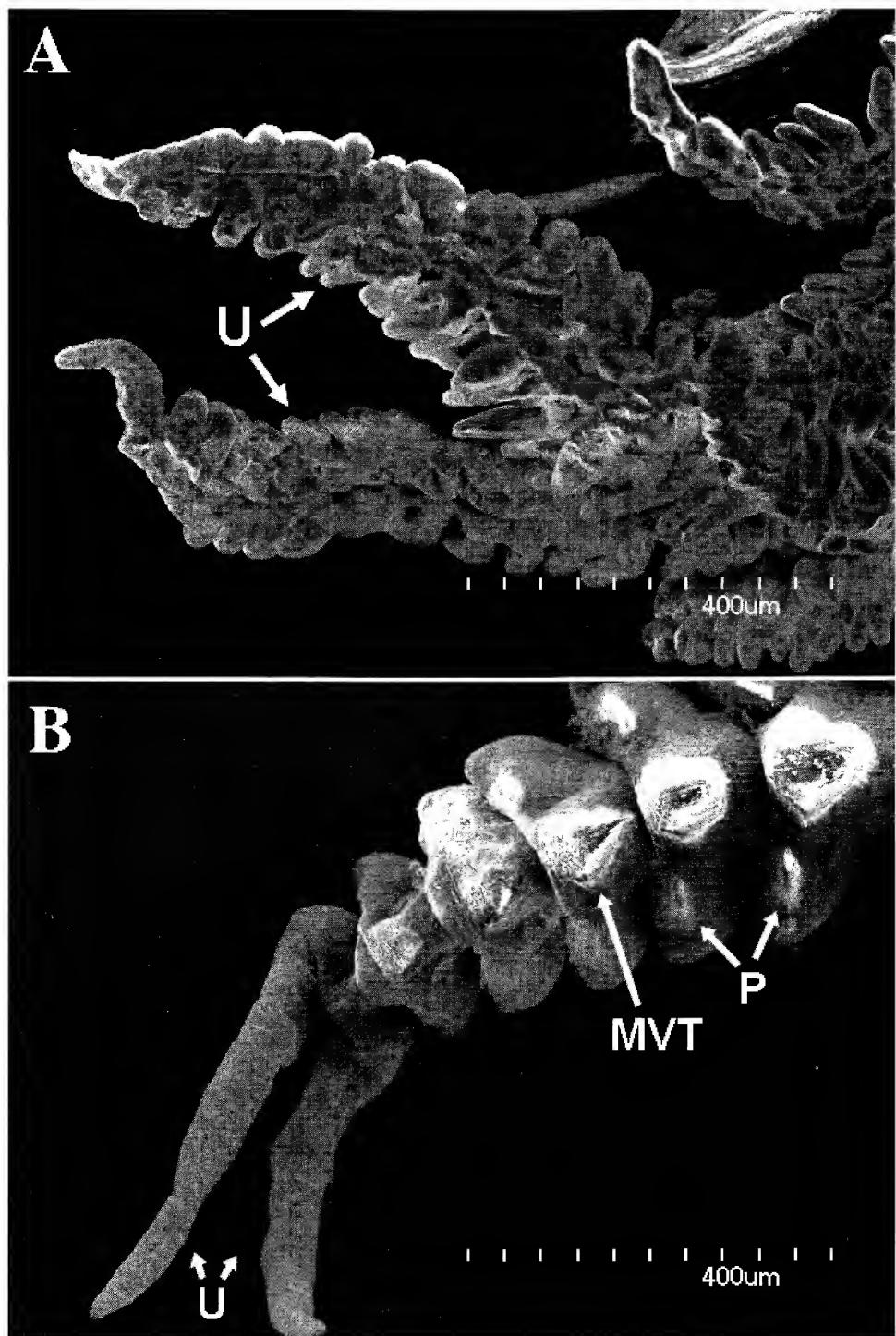
Figure 1. *Leidya bimini* Pearse, 1951. A) Female, 5.0 mm (destroyed); B) Male, 2.5 mm (destroyed), pleonites II-V and pleotelson. NW Gandy Bridge, Hillsborough County, Florida, USA, ex *Armases cinereum* (Bosc). MVT = midventral tubercle; P = pleopod; U = uropods.

by McDermott (1991). A collection of 39 specimens of *Armases ricordi* (H. Milne Edwards) from the same Tampa Bay stations contained no parasitized specimens (Mahon, pers. comm.), and attempts to find additional parasites on *A. cinereum* in March 2000 were unsuccessful (Mahon, personal communication).

Richardson (1908) stated that "the species found by Fritz Mueller in the branchial cavity of a Grapsoid *Pachygrapsus transversus* (Gibbes), from the coast of Brazil, is probably this species and genus ['*L. distorta*'], and not *Grapsicepon fritzii*, the nominal species of Giard and Bonnier [1887]." In fact, if the material of Müller (1871) is identical with *L. bimini* (*L. distorta* sensu Richardson), then *G. fritzii* Giard and Bonnier (1887) would be the same taxon as *L. bimini*, as pointed out by Markham (1979) in his synonymy list for *L. bimini*. However, *G. fritzii* is a nomen nudum from both Giard and Bonnier (1887: 63, 70) and Bonnier (1900: 266), and placement of this name into synonymy with *L. bimini* would not involve any change in the valid species name for the taxon. But while it is possible that *G. fritzii* and *L. bimini* are conspecific, it is equally possible that *G. fritzii* and *G. edwardsi* Bonnier, 1900, known from the grapsoid *Planes minutus* (Linnaeus) in Brazil, are actually the conspecific taxa in question. However, there have been no records of *L. bimini* from Brazil, nor any subsequent records of bopyrid parasites from Brazilian *Pachygrapsus*, and it is therefore best to treat *G. fritzii* as an indeterminable nomen nudum (herein) or perhaps a questionable synonym of *L. bimini* (Markham 1979).

### *Cardiocepon* Nobili, 1906

*Cardiocepon* Nobili 1906: 1104–1106, figure 3.—Bourdon 1967: 115.—Bourdon and Bowman 1970: 422.—Bourdon and Stock 1979: 216–217.—Bourdon 1981: 105.—Markham 1980: 628–629.

**Included species.** *C. pteroides* Nobili, 1906 (type species by monotypy).

**Host families and genera.** GECARCINIDAE: *Cardisoma* (Nobili 1906).

**Distribution.** Ternate, Indonesia.

**Remarks.** The sole species in this genus possesses peculiarly shaped, ventrally directed, pleopodal endopodites; these have short, stout, almost hook-like digitations; the exopodites are similar in size and shape to the lateral plates. Bourdon's (1981) suspicion that the supposed biramous epimeral plates as described by Nobili (1906) are, in fact, uniramous is confirmed, but the genus is valid nevertheless. Although the female of this species is similar to *Megacepon*, its prominent

dorsal bosses on pleonites II and III, coupled with the distinctive shape of the pleopodal endopodites, require its continued status as a separate genus. Additionally, the first oostegite is of an extreme elongated and foliaceous form greatly exceeding that found in either *Leidya* and *Megacepon*. As this species has not been reported subsequent to the holotype, and the description of Nobili (1906) was incomplete and partly inaccurate, the holotype (now damaged) is redescribed below.

### *Cardiocepon pteroides* Nobili, 1906
### Figure 2

*Cardiocepon pteroides* Nobili 1906: 1104–1106, figure 3.—Bourdon and Stock 1979: 217.—Markham 1980: 629.—Bourdon 1981: 105.

**Redescription.** Female (Figures 2A–H), based on holotype. Body length approximately 22.9 mm (specimen broken), maximal width 10.6 mm, head length 2.7 mm, head width 5.0 mm. Pereon essentially straight. All body regions and pereonites distinctly segmented.

Head broad, weakly produced with anterior lamina flattened along distal margin; dorsal surface of head strongly bilobed with lobes directed latero-dorsally (Figure 2A). Eyes absent. Antenna of 3 articles; antennule of 5 articles. Maxilliped (Figure 2B) with low rounded spur; distal segment subovate with mesiodistal narrow, acute nonarticulating palp.

Pereon composed of 7 pereonites, broadest across pereonites III and IV, tapering anteriorly and posteriorly. Coxal plates largest on pereonites II–IV, markedly smaller on pereonites I and V–VII. First oostegite proximal lobe subquadrate, distal lobe extremely elongate, broadening distally and becoming more pronounced; rounded, internal ridge with pronounced digitations (Figure 2C). Oostegites completely enclosing brood pouch; posteriormost oostegite surface faintly tuberculate with fringe of setae on posterior margin. Pereopods II–IV of about same size; pereopods I, and V–VII much smaller (Figure 2D). Basis of all pereopods bearing pronounced rounded medial boss. First pair of pereopods surrounding head region; small gaps between pereopods V–VII. Pereonite VI with large triangular, posteriorly directed, medial boss strongly overreaching pereonite VII and extending over pleonite I; other pereonites without bosses.

Pleon with 5 distinct pleonites plus pleotelson; pleonites II and III each with prominent medial, posteroventrally directed and distally rounded, dorsal boss (Figure 2E). Pleonites I–V with biramous pleopods and uniramous lateral plates; exopodites and lateral
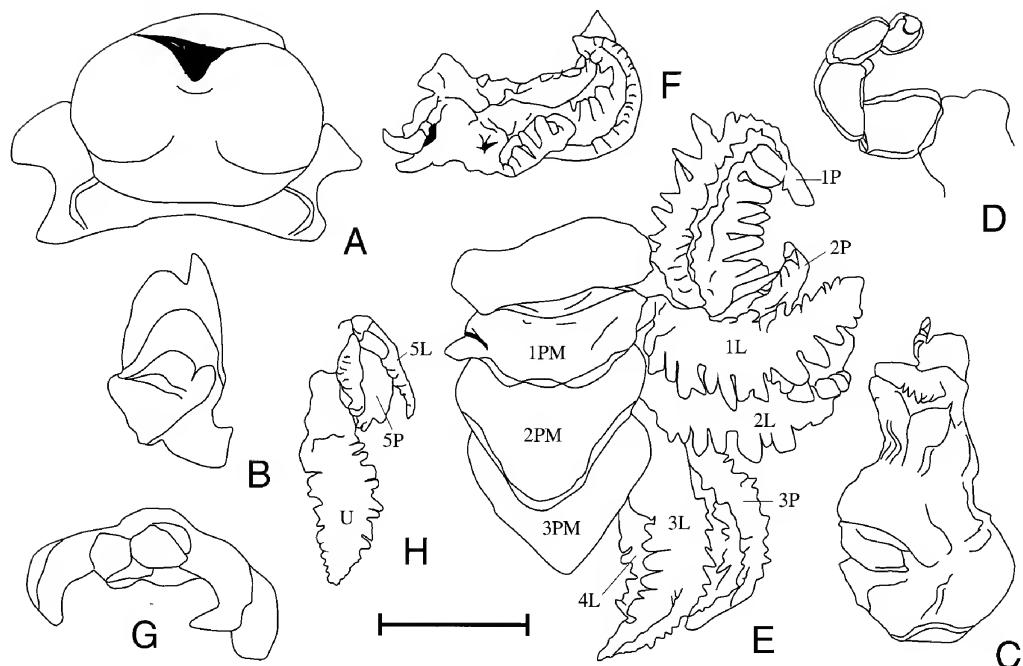
**Figure 2.** *Cardiocepon pteroides* Nobili, 1906. Holotype female, approximately 22.9 mm (MCSN): A) cephalon, dorsal view; B) right maxilliped, external; C) right oostegite I, internal; D) left pereopod VI; E) pleonites I–III, dorsal view; F) left pleopod and lateral plate I; G) endopod of pleopod II, ventral view; H) left uropod and pleopod V, ventral view. L = lateral plate; P = pleopod; PM = pleonite; U = uropod; numbers indicate pleon segment. Scale = 2.4 mm (F, G), 2.5 mm (D), 3.2 mm (A, B, E, H), 4.8 mm (C).

plates elongate and distally tapered with smooth dorsal surfaces, deep median furrow on ventral surfaces, and strongly digitate margins (Figures 2E, F); endopodites short, ventrally directed, with stout finger-like digitations (Figure 2G); lateral plates and pleopods on pleonites I–IV similar in size, reduced to less than 50% of length on pleonite V (Figure 2H); uropods uniramous, similar in size and shape to pleopodal exopodites I–IV (Figure 2H).

### *Megacepon* George, 1947

*Megacepon* George 1947: 385.—Bourdon 1967: 116.—Bourdon and Bowman 1970: 422.—Bourdon and Stock 1979: 216–217.—Markham 1980: 628–629.— Bourdon 1981: 105–107.—Markham 1982: 361.

**Included species.** *M. sesarmae* (Pearse, 1930) n. comb.; *M. goetici* (Shiino, 1934) n. comb.; *M. choprai* George, 1947 (type species by monotypy); *M. pleopodatopus* Bourdon, 1981.

**Host families and genera.** GRAPSIDAE: *Chiromantes* (*M. choprai*: Shiino 1958; *M. sesarmae*: Pearse 1930); *Episesarma* (*M. choprai*: Markham 1980); *Goetice* (*M. goetici*: Shiino 1934, Shiino 1958, Markham 1982); *Muradium* (*M. choprai*: George 1947); *Perisesarma* (*M. choprai*: Markham 1990); *Sesarma* (*M. choprai*: George 1947, Shiino 1958, Markham 1980, 1990; *M. sesarmae*: Pearse, 1930); *Varuna* (*M. pleopodatopus*: Bourdon 1981).

**Distribution.** India (*M. choprai*); Japan (*M. goetici*, *M. choprai*); Indonesia (*M. pleopodatopus*); Thailand (*M. choprai*); Hong Kong (*M. goetici*); China (*M. sesarmae*).

**Remarks.** Species in this genus possess an elongate first oostegite, a prominent mediodorsal boss on the first pleonite of the female, and a telson with moderately produced lateral lobes (not true uropods) on the male. The type species of *Megacepon* was redescribed by Shiino (1958, female) and Markham (1980, male), while Bourdon (1981) described a second species, although only conditionally assigning it to *Megacepon*. Bourdon and Bowman (1970) considered *Leidya sesarmae* and *M. choprai* as possibly conspecific, but the description of the male of *M. choprai* by Markham (1980) shows that they are not; they are, however, considered here to be congeneric. Bourdon and Stock (1979) described the taxon "?*Megacepon* sp. (aff. *Portunicepon goetici* Shiino, 1934)," which they suggested might be conspecific with *Portunicepon goetici*. This placement of *goetici* in *Megacepon* is supported by Markham's (1982) illustration of the first oostegite, although Markham

(1982) incorrectly placed Shiino's species in *Allokepon* (all of which have females with short first oostegites and lacking mediodorsal bosses on pereonites II–IV, and males with short lateral lobes on the pleotelson); see also remarks below under *Allokepon*. Comparison of the descriptions and illustrations of Bourdon and Stock's (1979) "aff. *goetici*" specimens with those of *M. goetici* indicates that these are two distinct taxa, but likely not congeneric, as Bourdon and Stock's (1979) taxon has a large mediodorsal boss on pleonite II, rather than on pleonite I as is found in all other *Megacepon* species. Correct placement of Bourdon and Stock's (1979) taxon is deferred until the specimens can be reexamined; it may require a new genus. The description for "aff. *goetici*" given by Bourdon and Stock (1979: 214–216, figures 7–8), requires a correction in that the mediodorsal bosses on the pereonites of the female are strongly produced on segments V and VI, not IV to VI.

### *Allokepon* Markham, 1982

*Allokepon* Markham 1982: 356–357.—Markham 1985: 38.—Markham 1989: 146 (juvenile characters).

**Included species.** *A. hendersoni* (Giard and Bonnier, 1888) (type species by original designation); *A. tiariniae* (Shiino, 1937) n. comb.; *A. monodi* (Bourdon, 1967); *A. sinensis* (Danforth, 1971).

**Host families and genera.** PORTUNIDAE: *Charybdis* (*A. hendersoni*: Bonnier, 1900); *Lissocarcinus* (*A. sinensis*: Danforth 1971, Markham 1982); *Portunus* (*A. sinensis*: Markham 1985, 1989); MAJIDAE: *Stenorhynchus* (*A. monodi*: Bourdon 1967, 1971); *Tiarinia* (*A. tiariniae*: Shiino 1937).

**Distribution.** India (*A. hendersoni*); Hong Kong, Thailand, and the Philippines (*A. sinensis*); Japan (*A. tiariniae*); Senegal and Dahomey (*A. monodi*).

**Remarks.** Markham (1982) erected this genus to contain four species originally placed in the genus *Portunicepon* Giard and Bonnier, 1887. These species were not congeneric with the type species of *Portunicepon* (which is a synonym of the type species of *Ergyne* Risso, 1816), and were assigned to their own genus, *Allokepon*, while *Portunicepon* was recognized as a synonym of *Ergyne*. Markham (1982) included one species (*A. goetici*) which has the unusual and clearly apomorphic elongate condition of the first oostegite. This species is herein removed to *Megacepon*, as it possesses all of the important characters of that genus (see above). Species of *Allokepon* possess a short first oostegite and prominent mediodorsal bosses on

pereonites VI and VII (lacking on pereonites I–V and all pleonites) of the females, although there is a specimen in the Paris Museum (MNHN) that appears referrable to *A. tiariniae* but has large mediodorsal bosses on pereonites IV–VII; this specimen requires more study and is not otherwise discussed herein. Markham, in his 1982 redescription of the holotype of *A. sinensis*, indicated that the middorsal bosses occurred on pereonites V and VI, but Danforth (1971) described them on VI and VII. Markham (1982) excluded two species of "*Portunicepon*" from *Allokepon* but did not suggest proper generic placement for either. Based on literature descriptions and illustrations only, there appears to be no reason not to place *Portunicepon tiariniae* Shiino, 1937, in *Allokepon*, in spite of the peculiarly-shaped telson of the male. I agree, however, that *P. savignyi* (Stebbing, 1910), with its prominent mediodorsal bosses on pereonites V–VII (lacking on pereonites I–IV and all pleonites), does not belong in *Allokepon* nor apparently any other genus discussed herein; it may require its own genus. The same may also be true of *A. sinensis* sensu Markham (1985), which has mediodorsal bosses on pereonites VI and VII, as well as pleonites I and II. However, until the specimens can be reexamined, the current status should be maintained and *A. sinensis* sensu Markham (1985) is retained in *Allokepon* for the present, while "*Portunicepon*" *savignyi* is excluded (and remains unplaced).

### PHYLOGENETIC RELATIONSHIPS

The peculiar elongate shape of the first oostegite is a synapomorphy shared by the Ioninae genera *Leidya*, *Megacepon* and *Cardiocepon* (see also Bourdon and Bowman 1970), the prominent mediodorsal boss in an unusual location on the first pleonite of the female is a synapomorphy for *Megacepon*, and the long "uropods" of males is a synapomorphy for *Leidya*. It is more difficult to find a synapomorphy for *Allokepon*, except perhaps the presence of mediodorsal bosses only on pereonites VI and VII (but this would exclude *A. sinensis* from the genus). Together these four genera appear to comprise a distinct clade, but further elucidation of the exact relationships between these genera and other Ioninae must await a comprehensive phylogenetic analysis based on type specimens of all taxa.

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# Population Biology of the Ghost Shrimp *Sergio trilobata* (Biffar 1970) (Crustacea: Decapoda: Thalassinidea)

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# POPULATION BIOLOGY OF THE GHOST SHRIMP *SERGIO TRILOBATA* (BIFFAR 1970) (CRUSTACEA: DECAPODA: THALASSINIDEA)

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ABSTRACT *Sergio trilobata* is a common burrowing crustacean found in Tampa Bay, Lemon Bay, and Miami, Florida, where it inhabits mainly intertidal soft sediments (Biffar 1971, Manning and Lemaitre 1993). Although *S. trilobata* is a dominant member of the benthic community, very little is known about population dynamics and reproduction of these thalassinideans. The population biology of this ghost shrimp was examined over a period of a year and a half to gain understanding of its life history. Seasonal variation in the proportion of individuals in each size class was observed during the study, suggesting that there may be environmental factors affecting the ghost shrimp. Additionally, a life span of approximately two years is indicated by the seasonal variation in the proportion of individuals in each size class. The population was biased toward females with a 1:1.81 male: female ratio, and the mean total length of females (68.2 mm) was larger than the males collected (54.6 mm) ($P = 0.0001$). Collection of ovigerous females were directly correlated with an increasing ovary width of females during the preceding months, and the total length of *S. trilobata* was positively correlated with the number of eggs produced. Mean number of eggs per female *S. trilobata* was 197 with a maximum of 412 eggs.

## INTRODUCTION

Ghost shrimp are decapod crustaceans that construct and inhabit burrows predominantly in shallow intertidal regions containing a soft sediment base (Felder and Manning 1997, Kevrekidis et al. 1997, Berkenbusch and Rowden 1999). These thalassinideans also commonly inhabit regions with a high content of organic matter (Felder and Manning 1997) which has been known to trigger settlement in some species of ghost shrimp (Strasser and Felder 1999). Ghost shrimp are frequently found in both tropical and temperate regions (Berkenbusch and Rowden 1999), and are an important component of the ecosystem due to their bioturbating activities, which impact nutrient cycling (Nates and Felder 1998), sediment turnover rates (Felder and Griffis 1994), benthic community structure (Dittmann 1996) and commercial industries such as aquaculture (Davey et al. 1990, Lemaitre and Rodrigues 1991, Lafferty and Kuris 1996, Nates and Felder 1998, Berkenbusch and Rowden 2000, Felder 2001).

*Sergio trilobata* (Biffar 1970) is a common burrowing crustacean in Tampa Bay that inhabits mainly shallow intertidal soft sediment habitats (Biffar 1971) and dominates the benthic community in mid to lower bay regions. *S. trilobata* was described from Tampa Bay but has also been reported from Miami and Lemon Bay, Florida (Biffar 1971, Manning and Lemaitre 1993). Collections of this species have been made in Tampa Bay at a water depth of approximately 2–4 meters (Biffar 1971). *S. trilobata* is also thought to thrive in

regions of high organic content and construct a thicker burrow wall than do other species of thalassinidean shrimp in South Florida (Biffar 1971).

Environmental conditions such as temperature and salinity have been recognized to impact intertidal decapod crustaceans (Tamaki et al. 1997, Berkenbusch and Rowden 1999). Low temperatures may cause shrimp to be relatively inactive, resulting in a decrease in sediment turnover rates, decreasing the impact of these organisms on their environment (Berkenbusch and Rowden 1999). Salinity may also be a factor in the distribution of this species, since *S. trilobata* is usually found in mid to high salinities and is then replaced by *Lepidophthalmus louisianensis* in areas of low or more fluctuating salinities (Felder 1978, Felder and Rodrigues 1993) and higher sedimentary organic content (unpublished data).

Members of the genus *Sergio* are considered to be diverse ecologically and may vary with respect to reproductive and life history characteristics such as development and dispersal activities (Nates et al. 1997). It is known that varied symbiotes such as copepods, pea crabs, caridean shrimp, clams, and gobiid shimp are commonly found in the burrows of ghost shrimp (Jackson 1996). Although *Sergio trilobata* is a dominant member of the benthic community, very little is currently known about this species. The present study undertakes observations of population dynamics and reproductive characteristics in this poorly known but dominant member of the Tampa Bay benthic community.

## Materials and Methods

Monthly collections of *Sergio trilobata* were made on an intertidal sand flat located on the southwest end of the Gandy Bridge in Tampa Bay, Florida (27.87N, 82.60W) from April 2000 to August 2001. Specimens were obtained by extracting animals from randomly chosen burrow holes in a sub-area of the intertidal sand flat using yabby pumps to extract samples, which were then washed over 1-mm mesh sieves (Felder 1978). At least 15 animals were collected during each collection. Each individual organism was placed in a clean whirl pack® plastic bag and returned to the laboratory for examination. The proportion of individuals in each size class (10 mm increments) was examined on a seasonal basis, with three months being included in each season: spring (March, April, May), summer (June, July, August), fall (September, October, November), and winter (December, January, February).

The sex of the animal, total length (TL, measured from the tip of the rostrum to the posterior end of the telson in live specimens), and carapace length (CL, measured from the tip of the rostrum to the posterior end of the carapace) were recorded for each individual. All measurements were made to the nearest millimeter. Although specimens as small as 10.5 mm TL were collected, individuals below approximately 30 mm in total length could not be sexed and were classified as juveniles. Female ovary width was measured on the second abdominal segment at the widest point visible through the transparent dorsal integument of the second abdominal somite, and the number of eggs was also recorded for each female when ovigerous. Females thought to be releasing eggs during the time of collection were excluded because it was thought they would bias the results. Females classified as thought to be releasing eggs were those that had a small number of well developed eggs remaining on the pleopods and had obviously released the remainder of the brood. This resulted in the exclusion of a maximum of 10–15 specimens throughout the entire study. Eggs were also categorized according to their color (red orange, orange, yellow orange, or yellow) and whether or not they contained visible eyespots. After measurements were recorded, specimens were archived in 70% ethanol.

## Results

The proportion of individuals in each size class varied seasonally (Figure 1). In spring 2000 the population was dominated by individuals in the larger size classes of 60–89 mm and included only a very small proportion of individuals in the smaller size categories of 20–39 mm (Figure 1A). Samples in summer of 2000 exhibited a larger proportion of the population in the smaller size categories, but most individuals were still in the 60–79 mm size range (Figure 1B). During the fall, no organisms were present in the largest size class (80–89 mm). Also in this period, the 60–69 mm size class contained the highest proportion of the population, which may represent individuals recruited into the population during the previous spring (Figure 1C). In winter 2000 and spring 2001, there were no individuals present in the smallest size class, and the highest proportion of the population was again in the 60–79 mm size classes (Figures 1D and 1E). A bimodal distribution is present in both of these seasons, which may again represent the presence of two distinct generations. As in the previous year, in summer 2001 the highest proportion of individuals was observed in the 70–79 mm size category, and there is an increase in the proportion of larger individuals in the 80–89 mm size category (Figure 1F). Although collections in the fall of 2001 were limited to September and October, once again, no organisms in the largest size class of 80–89 mm were represented in the sample.

The population of *S. trilobata* was biased toward females with a ratio of 1:1.81. Males ranged in total length from 31 to 82 mm with a mean (± SE) of 54.6 ± 5.4. Females had a mean (± SE) length of 68.2 ± 2.2, ranged in total length from 34 to 88 mm, and were significantly larger than males ($P = 0.0001$) when compared with a Mann Whitney U Test. Although variable, this difference in size was consistent over the entire sampling period (Figure 2) with the exception of October 2000.

Ovigerous females were collected from April through October 2000, and March through August 2001 (Figure 3A). During the months of April and May in both years, the proportion of ovigerous females collected was larger than during the rest of the year. The time period during which ovigerous females were present can be directly correlated with the ovary width of the females during the preceding months. During the months of November 2000 to February 2001, when no ovigerous females were collected, a peak in mean ovary width of females was observed. There was also a decline in mean ovary width starting in March and continuing through June, when the highest proportion of ovigerous females were collected (Figure 3B).

The average number of eggs collected per female was 197 ± 18.1 eggs, and a positive correlation existed

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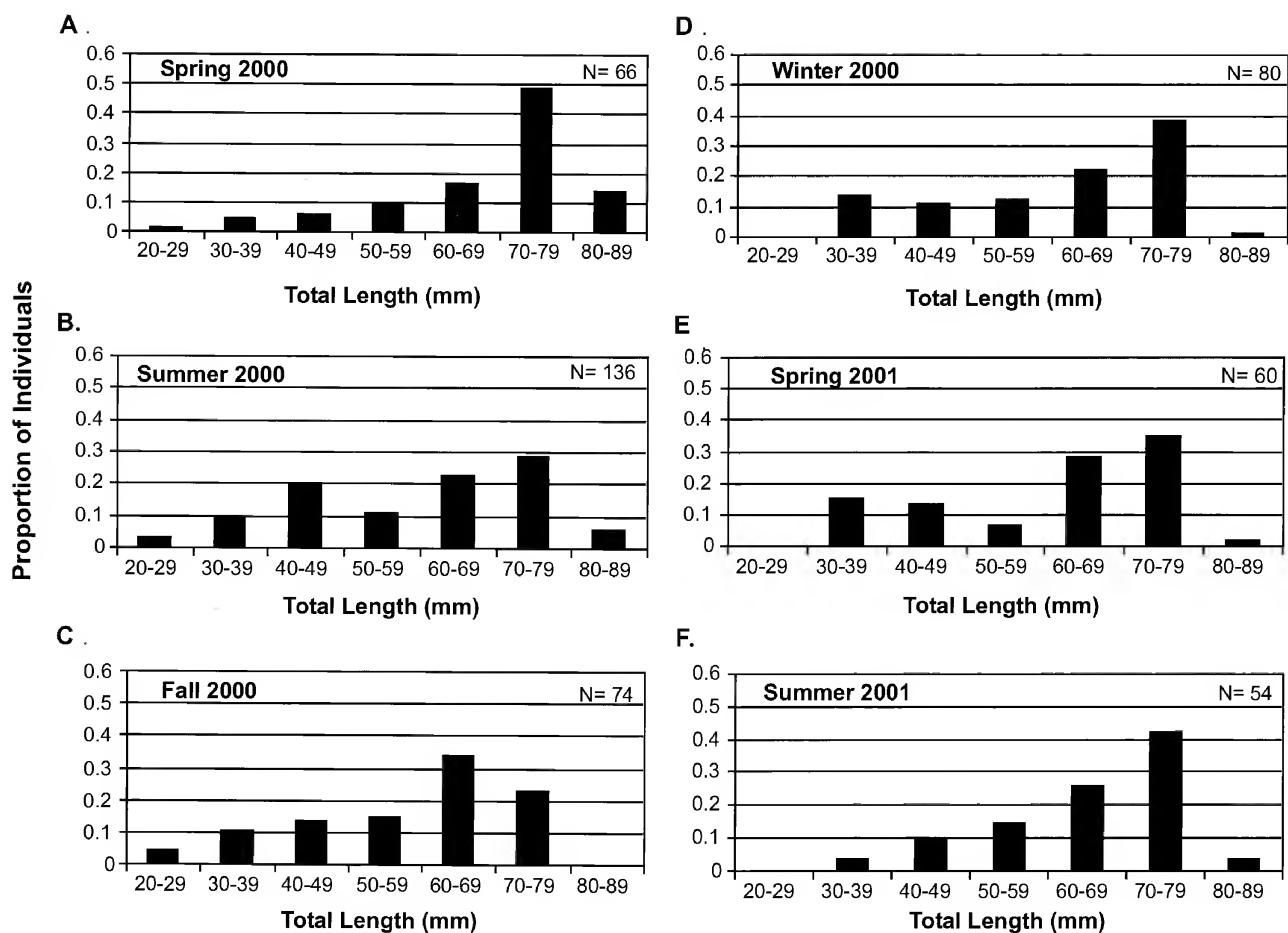
**Figure 1. Seasonal variation in the proportion of** *Sergio trilobata* **in each of six 10-mm total length size categories: A) Spring 2000; B) Summer 2000; C) Fall 2000; D) Winter 2000; E) Spring 2001; F) Summer 2001.**

between number of eggs per female and its total length ($r^2 = 0.929$, $n = 56$) (Figure 4). The highest fecundity observed was 412, although this may be an underestimate of potential fecundity as some eggs may be lost in the collection process. Eggs ranged in color from red-orange immediately after release from the ovary to a pale yellow containing distinct eyespots in the days prior to hatching. The smallest female found to be ovigerous was 48 mm in total length with 62 eggs, and the smallest female collected with developed ovaries was 41 mm in total length with ovaries 2 mm wide.

## DISCUSSION

Seasonal variation in the proportion of individuals in each size class was observed during the study suggesting that there may be environmental factors affecting the ghost shrimp. Additionally, a life span of approximately two years is indicated by the seasonal variation in the proportion of individuals in each size.

The bimodal distribution of the population in winter 2000 and spring 2001 indicate the presence of two generations in the burrowed population. Maturity of those recently recruited then follows the next year as ovigerous females are most commonly found in the spring and summer. These observations along with the apparent mortality in the largest size classes in fall 2000 and 2001 suggest the life span of these organisms may be limited to two years. The life span of thalassinidean shrimp is variable, but there are some that have comparable life spans of two years, such as with *Lepidophthalmus louisianensis* (Felder and Lovett 1989), *Callianassa japonica* (Tamaki et al. 1997), and *Callianassa kraussi* (Forbes 1977). Some other thalassinidean shrimp exhibit a longer life span of approximately 3–4 years such as *Upogebia pusilla* (Kevrekidis et al. 1997), *Sergio mirim* (Pezzuto 1998), and *Callianassa filholi* (Berkenbusch and Rowden 2000). The seasonal variation in the proportion of individuals in each size class in the population is also related to the
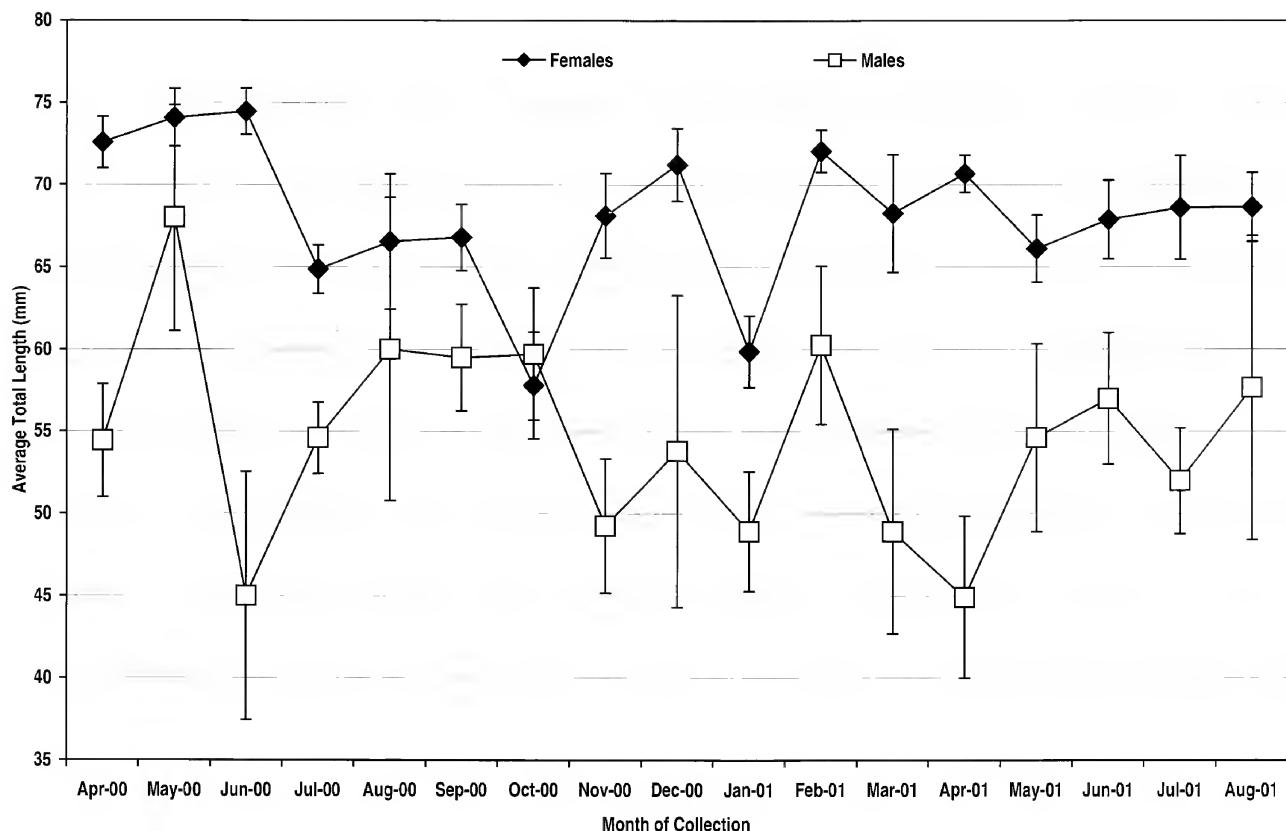
**Figure 2. Mean total length (± SE) of male (*n* = 138) and female (*n* = 297) *Sergio trilobata* during each month of collection (April 2000 to August 2001).**

fecundity of the organisms and recruitment of juveniles into the population. Fecundity and recruitment may be affected by temperature or salinity fluctuations, although the exact cause of these variations warrants further study. Salinity was found to range from 25 to 38‰ but does not seem to impact the reproductive output of *S. trilobata* as the fluctuations in salinity did not mirror trends in reproduction. Although exact temperatures were not recorded on a regular basis, seasonal temperature changes were the most likely cue for reproduction since data collected does indicate a seasonal trend in ovary size and egg production of females. However, even if surface water temperatures were collected, they might have been misleading since the water temperature in the burrows is often lower than the surface water temperature.

The population of ghost shrimp was found to be biased toward females with a 1: 1.81 male:female ratio. Sex ratios have been found to be variable in other thalassinidean shrimp; for example, *Sergio mirim* (Pezzuto 1998), *Lepidophthalmus louisianensis* (Felder and Lovett 1989, Felder and Griffis 1994) *Lepidophthalmus sinuensis* Lemaitre (Nates and Felder

1999), *Callianassa filholi* (Devine 1966, Berkenbusch and Rowden 2000), *Callianassa japonica* Ortmann (Tamaki et al. 1997), *Callichirus armatus* (Vaugelas et al. 1986), and *Callichirus islagrande* (Felder and Griffis 1994) exhibit a female biased sex ratio. The sex ratio has also commonly been reported as male biased in other species such as with *Callichirus kraussi* (Forbes 1977) and *Callianassa subterranea* (Rowden and Jones 1994). The variability in the sex ratio of ghost shrimp can be attributed to many factors including seasonal variation and variation between species (Berkenbusch and Rowden 2000). The variability may also have a behavioral basis; for example, females with eggs are often found closer to the burrow entrance than males, which would make them more susceptible to collection (Nates and Felder 1999).

The mean TL of females was larger than the males collected from April until October 2001, with the noted exception of October 2000. Populations in which females are larger than males is comparable with other thalassinidean shrimp such as *Callianassa filholi* (Berkenbusch and Rowden 2000) and *Sergio mirim* (Pezzuto 1998) in which the females collected were also

**A.**



**B.**
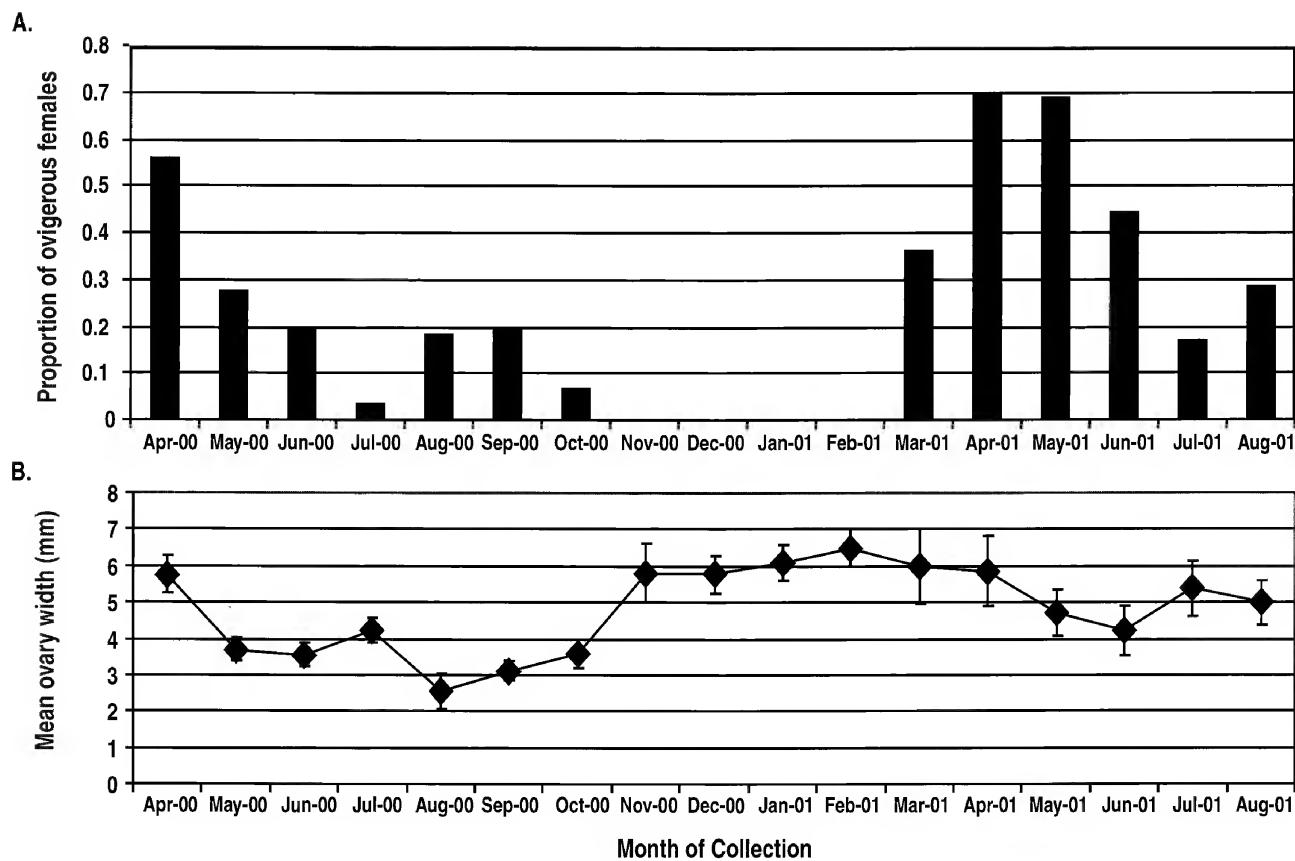


Figure 3. Reproductive data for *Sergio trilobata* from April 2000 to August 2001: A) Proportion of female sample ovigerous during each month of collection; B) Mean ovary width (± SE) of females during the collection period.



y = 53.136x - 64.227
$R^2$ = 0.9287
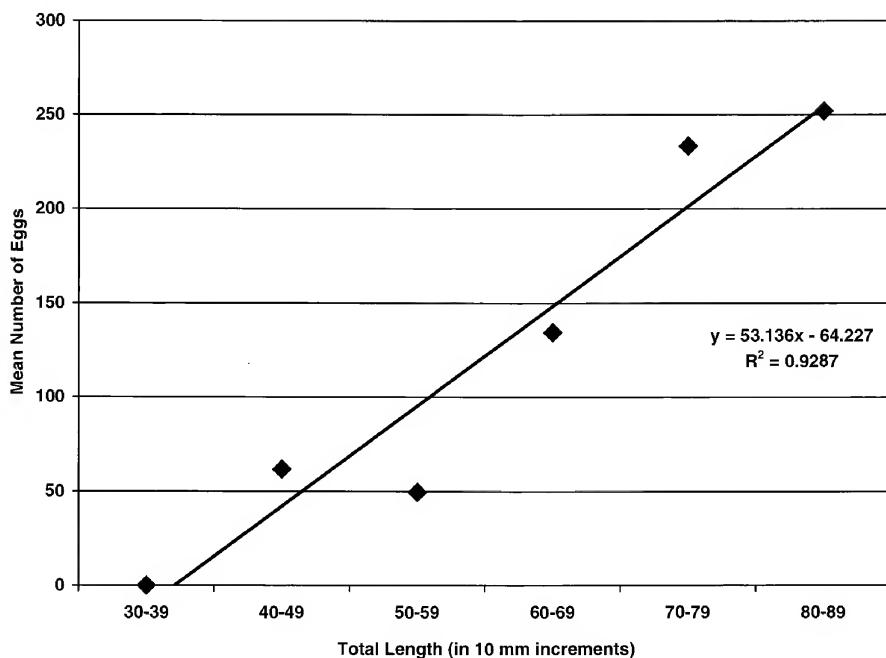
Figure 4. Mean number of eggs per females of *Sergio trilobata* in each of six 10-mm total length (TL) size category.

## TABLE 1

**Comparison of the mean and maximum number of eggs of female thalassinidean shrimp in selected studies. (– ) indicates no value was provided in reference.**

| Species | Mean Egg No. | MaximumEgg No. | Reference |
|---|---|---|---|
| *Sergio trilobata* | 197 | 412 | present study |
| *Lepidophthalmus sinuensis* | 251 | 958 | Nates and Felder 1999 |
| *Callianassa tyrrhena* | 270 | 1188 | Thessalou-Legaki and Kiortisis 1997 |
| *Callianassa japonica* | 331 | 962 | Tamaki et al. 1997 |
| *Lepidophthalmus louisianensis* | 598 | – | Nates et al. 1997 |
| *Sergio mirim* | – | 6586 | Pezzuto 1998 |
| *Callichirus major* | – | 8710 | Pohl 1946 |

larger in mean size than the males in the population. There are, however, many thalasinidean shrimp in which the males exhibit a larger mean TL than the females such as *Upogebia pusilla* (Kevrekidis et al. 1997) and *Callianassa japonica* Ortman (Tamaki et al. 1997). In many cases when males are larger than females in the population, the size difference can be attributed to male to male competition. However, in this case males were found to be smaller than females providing no evidence of intrasexual selection or sex-related mortality which would cause the female biased population.

The increased proportion of ovigerous females can be directly correlated with an increasing ovary width of the females during the preceding months. During the summer months, the proportion of ovigerous females increases as the mean ovary width decreases. Correlations between the mean ovary width and the proportion of ovigerous females in populations of ghost shrimp has also been observed in other thalassinidean shrimp such as *Lepidophthalmus louisianensis* (Felder and Griffis 1994), *Lepidophthalmus sinuensis* (Nates and Felder 1999), *Callianassa japonica* (Tamaki et al. 1997) and *Neotrypaea californiensis* (Dumbauld et al. 1996). The total length of *S. trilobata* was also found to be positively correlated with the number of eggs produced, which is similar to results found with many other ghost shrimp species such as *Callianasa tyrrhena* (Thessalou-Legaki and Kiortisis 1997), *Callianassa filholi* (Berkenbusch and Rowden 2000), and *Sergio mirim* (Rodrigues 1971) (Pezzuto 1998). The mean and maximum number of eggs per female *S. trilobata* (mean = 197, max. = 412) was slightly lower than other species of ghost shrimp, although the mean number of eggs per female in thalassinidean shrimp can be highly variable (Table 1). A low number of eggs per female is indicative of year round reproductive activity or multiple broods

produced per female annually, as well as large egg size (Thessalou-Legaki and Kiortsis 1997, Nates and Felder 1999, Berkenbusch and Rowden 2000). Although year round reproductive activity is not likely in *S. trilobata*, due to the apparent seasonal trends in reproduction, the possibility that *S. trilobata* produces multiple broods in a given breeding season cannot be eliminated. Additionally, although egg size was not measured in this study, eggs were found to be much larger than that of a sympatric species of ghost shrimp, *Lepidophthalmus louisianensis* (personal observation). Egg size has been directly correlated with larval development in many species of ghost shrimp in which species with larger eggs exhibit abbreviated development in larval stages (Forbes 1973). The egg size and number of broods produced annually would be of significance in determining the fecundity and the development of larval stages of *S. trilobata* and therefore warrant further study.

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# Gulf and Caribbean Research

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# Feeding Selectivity of *Anchovia clupeoides* (Pisces: Engraulidae) in the Ciénaga Grande de Santa Marta, Colombian Caribbean

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# FEEDING SELECTIVITY OF *ANCHOVIA CLUPEOIDES* (PISCES: ENGRAULIDAE) IN THE CIÉNAGA GRANDE DE SANTA MARTA, COLOMBIAN CARIBBEAN

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ABSTRACT Food selection by fishes is an important piece of information for modeling food webs in aquatic ecosystem. Monthly collections were made over a twenty-four hour period between October 1995 and June 1996 to examine the feeding selectivity of the zabaleta anchovy (*Anchovia clupeoides*) in the coastal lagoon Ciénaga Grande de Santa Marta, NE Colombia. A total of 4,389 specimens were collected, and the abundances and weights of the stomach food items were compared with similar measures calculated from samples obtained in nearby habitats. Our results indicate that the zabaleta anchovy is planktophagous, actively selecting copepods and detritus throughout the year. Individuals also exhibit positive selectivity of fish eggs and crab zoea on a seasonal basis and at different times of the day. This species avoids cyanobacteria, diatoms, and rotifers most of the year and during most of the day and always avoids copepod nauplii, polychaete larvae, and cladocerans. It seems that selection and avoidance of the food items by the zabaleta anchovy is due mainly to its preference for prey over 125 μm.

## INTRODUCTION

Selective feeding by fish means the preference or avoidance of certain available food components (Berg, 1979). To assess selectivity, two factors should be considered when examining food habits of a species: preference for given food types and availability of potential food items. By taking these factors into account one can examine the prey selectivity of a species (Prejs and Colomine 1981). Selectivity is defined as the ratio of the proportion of a given food item ingested to the proportion of that food item in the surrounding habitat. Selectivity depends heavily on the behavior of the predator and prey species (Caddy and Sharp 1988).

Predators may directly impact prey populations, which may in turn influence predator populations (Levinton 1995). Consequently, the alteration of a single predator-prey interaction has the potential to alter the structure of an entire community (Greenstreet and Tasker 1996). Abiotic factors may also play an important role in determining selectivity, since these factors may influence the distribution of potential prey. Periods of targeted feeding important to a population often coincide with a large influx of potential food (Nikolsky 1965).

The engraulid, *Anchovia clupeoides* (Swainson 1839) is an important fish to the pelagic food web in the Ciénaga Grande de Santa Marta (CGSM), Colombia (Duque and Acero 2003). The CGSM estuarine lagoon system is located on the Colombian Caribbean coast,

and it is part of the exterior delta of the Magdalena River (Figure 1). To the east, the CGSM is surrounded by the lower hills of the Sierra Nevada de Santa Marta, which reaches an elevation of about 5,800 m above sea level. From this region flow three main rivers that drain into the CGSM. The lagoon is separated from the Caribbean Sea by a barrier island, Isla de Salamanca, and is only connected to the sea by a 200 m wide opening called "Boca de la Barra." To the west and south, the lagoon borders the Magdalena River muddy plains (Wiedemann 1973, Cosel 1986, Botero 1988, Botero and Mancera 1996). The CGSM, with a width of 450 km and a mean depth of 1.5 m (IGAC 1973), has historically been the primary region targeted by local fishermen along the northern coast of Colombia (Santos-Martínez and Acero 1991). Species targeted include shrimp, oyster, crabs, and various fish species (Santos-Martínez and Viloria 1996). The main objective of this research was to determine the feeding selectivity of *A. clupeoides*, a key species in the trophic complex of the pelagic zone in the CGSM.

## METHODS

Monthly sampling trips were made between October 1995 and June 1996 to the CGSM. During each trip, samples were collected every three hours during a twenty-four hour period, resulting in eight samples per trip. Fishes were collected using a 150 m long and 2 m deep
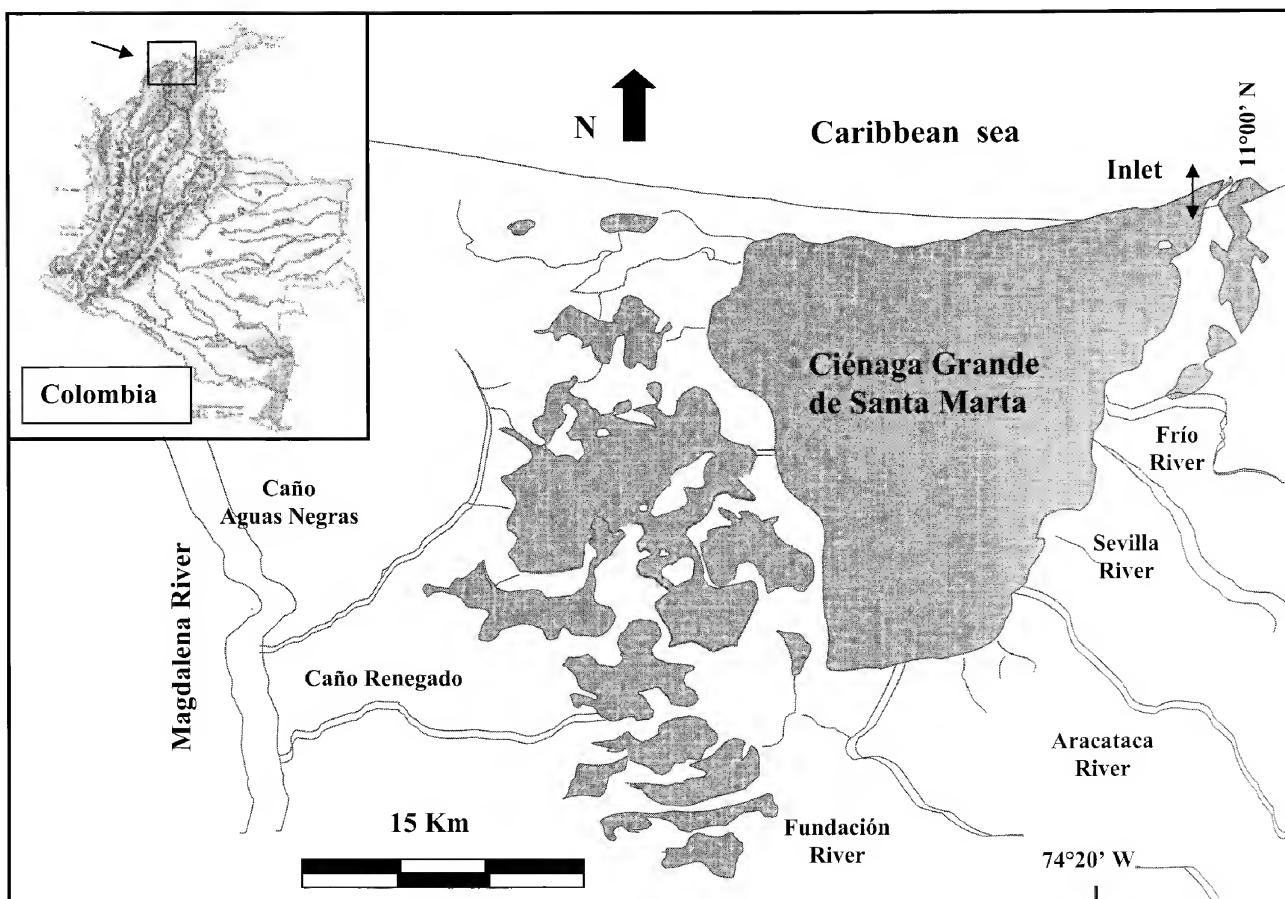
Figure 1. Map of the Ciénaga Grande de Santa Marta, Colombian Caribbean.

nylon monofilament gill net. Mesh sizes were equally distributed between 1.27 cm and 2.54 cm, following the experimental fishing methodology of Rueda and Mancera (1996).

To estimate abundance and biomass of the plankton groups in the fishing area, we collected plankton samples with a suction pump. Eighty liters of seawater were pumped and filtered through 250, 125, and 63 μm sieves. In the laboratory, fish samples were sorted into 5 mm size classes, and the total weight (g) and frequency for each size class was measured. Stomach contents of each individual were removed and passed through 250, 125, and 63 μm sieves. Using a microscope, the stomach contents of A. clupeoides and the plankton samples retained on each sieve were identified into large taxonomic groups and the total number of each group was recorded. All stomach and plankton fractions retained by the sieves were dried for 24 hours at 60°C and weighed (g).

The percentage composition by number (Windell and Bowen 1978) of the ingested food by A. clupeoides and the potentially available food (plankton samples in the fishing area) was calculated as:

$$\%N = (n/N) * 100;$$

where $\%N$ is the percentage composition by number, $n$ is the number of food items or plankton of a given taxonomic group in a given stomach or water sample, and $N$ equals the total number of food items or plankton in the stomach or water sample.

The selectivity of a given food item was estimated using the logarithmic version of Shorigin's index (Berg, 1979):

$$S = \log_{10} (\%N_1 / \%N_2)$$

where S is the transformed Shorigin selectivity index, $\%N_1$ is the percentage composition by number of the ingested food, and $\%N_2$ is the percentage composition by number of the plankton in the fishing area. If S > 0, the item is being actively selected by the fish; if S < 0, it is being avoided. Calculations of percentage compo-

sition by weight of the ingested food (mg) and the potentially available food (mg/l), and its respective selectivity, were also conducted as above.

## RESULTS

Ten planktonic groups were ingested by *A. clupeoides*. The comparison of the percentage composition by number and weight is presented in Figures 2a and 3a. Annual means of Shorigin selectivity index suggest that *A. clupeoides* selected copepods, fish eggs, detritus, and crab zoea (Figure 2b), whereas individuals avoided cyanobacteria, cladocerans, diatoms, copepod nauplii, polychaete larvae, and rotifers.

However, there were some slight differences in selectivity and avoidance of the food ingested by *A. clupeoides* when the annual mean is compared with calculations by month and time of day. Cyanobacteria, diatoms, and rotifers were selected in some of the months of the study, and crab zoea were avoided in October, January, and April (Table 1a). Moreover, the same food items were also selected and avoided at different times of the day (Table 1b).

Results of percentage composition by weight suggest that most of the food ingested by *A. clupeoides* was dominated by individuals larger than 250 μm (Figure 3a), that consisted primarily of copepods. According with the annual mean of Shorigin's index by weight, *A. clupeoides* selected items larger than 125 μm and avoided items between 63 and 125 μm (Figure 3b).

The weight of the food items was recorded only during the last seven months of the study (December to June). Shorigin's index by weight suggests that *A. clupeoides* selected items larger than 250 μm, avoided some items between 125 and 250 μm, and avoided all the items between 63 and 125μm (Table 2).

## DISCUSSION

Many physical and biological factors affect the selective behavior of fishes, but the most important are the movement and the size of prey (Leong and O'Connell 1969, O'Connell 1972, Angelescu 1982). Engraulids typically feed either by filtering prey items from water or by actively capturing prey. Choice of prey capture methods is determined by both the density and size of available prey (Leong and O'Connell 1969, O'Connell 1972). The predominant mode of feeding utilized by a species is important in determining the energetic needs and trophic level of the species as a whole (Blaxter and Hunter 1982). It seems that in the CGSM, *A. clupeoides* feeds during the day and night by active predation on preferred prey items, such as copepods and fish eggs. This may be driven by the annual availability of these prey.

The presence of detritus in the stomach of *A. clupeoides* appears to be accidental, and individuals may be unable to sort it from larger prey items due to its small size and high abundance in the CGSM. Leong and O'Connell (1969) suggested that engraulids cannot avoid detritus due to the nature of the filtration mechanisms
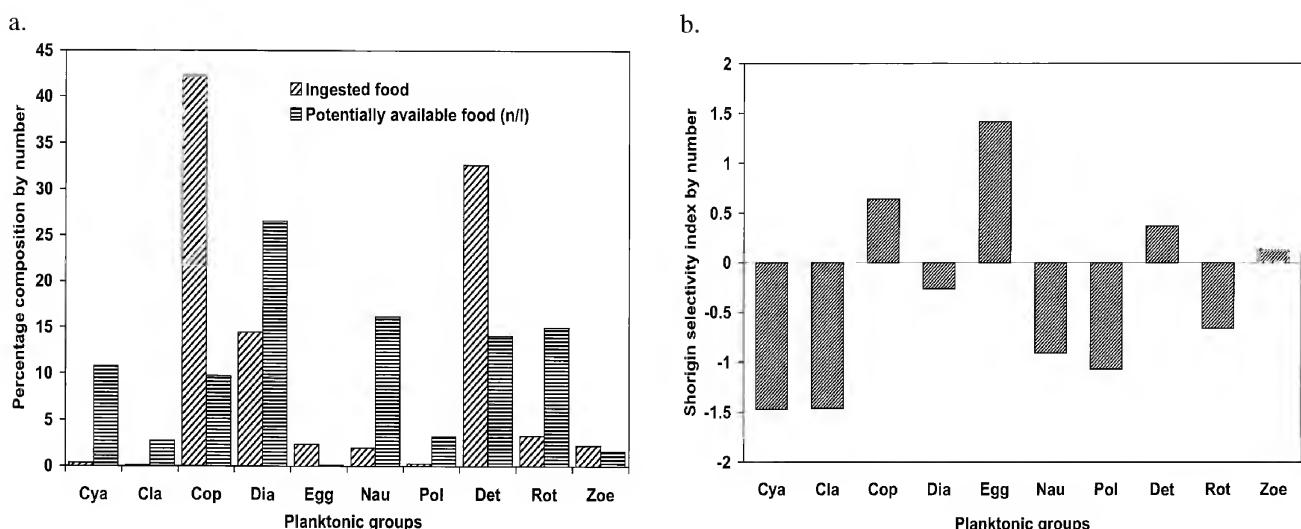


Figure 2. Comparison of the mean percentage composition by number of the food ingested by *Anchovia clupeoides* and the mean percentage composition by number of the potentially available food (a). Mean Shorigin selectivity index by number (b). Abbreviations for taxonomic groups are: copepods (Cop), detritus (Det), diatoms (Dia), rotifers (Rot), fish eggs (Egg), crab zoeas (Zoe), copepod nauplii (Nau), polychaete larvae (Pol), cyanobacteria (Cya), and cladocerans (Cla).

a.
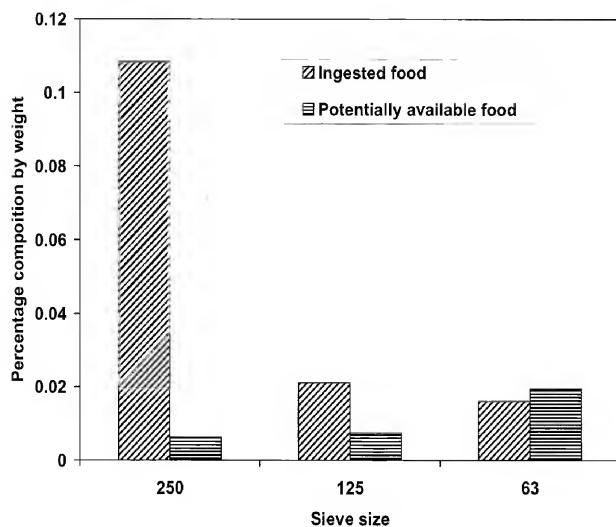


b.
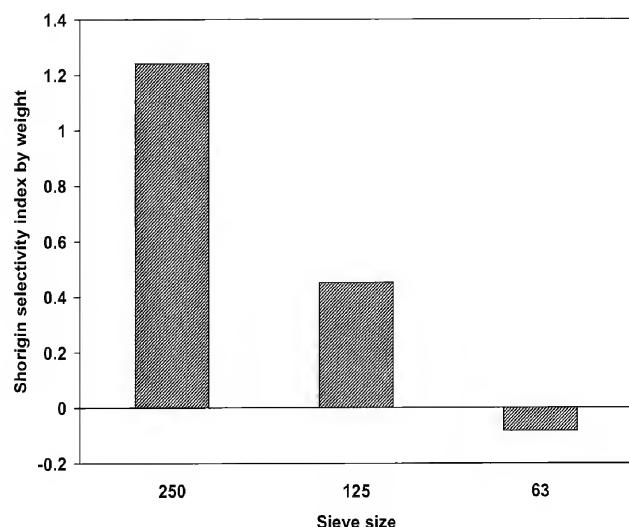


Figure 3. Comparison of the mean percentage composition by weight of the food ingested by *Anchovia clupeoides* and the mean percentage composition by weight of the potentially available food (a). Mean Shorigin selectivity index by weight (b). Sieve sizes in microns.

## TABLE 1

Shorigin's feeding selectivity index of *Anchovia clupeoides* by month (a), and time of the day (b). Abbreviations for taxonomic groups are: copepods (Cop), detritus (Det), diatoms (Dia), rotifers (Rot), fish eggs (Egg), crab zoeas (Zoe), copepod nauplii (Nau), polychaete larvae (Pol), cyanobacteria (Cya), and cladocerans (Cla). There are blanks when the specific planktonic group was not found in the fish stomachs at a specific month or time of the day.

a.

| Month | Cya | Cla | Cop | Dia | Egg | Nau | Pol | Det | Rot | Zoe |
|---|---|---|---|---|---|---|---|---|---|---|
| October | 1.4 | | 0.7 | 0.2 | 1.4 | | -0.4 | | -0.7 | -0.1 |
| November | 1.6 | -0.9 | 0.2 | 0.3 | | -2.2 | -0.4 | | -0.6 | 1.1 |
| December | -1.1 | | 1.0 | 0.2 | | -1.0 | -0.9 | | 0.0 | 0.6 |
| January | -1.0 | -1.0 | 0.6 | -0.3 | | -2.4 | -0.9 | 0.3 | 0.7 | -0.6 |
| February | -1.2 | -0.7 | 0.4 | -0.2 | 0.2 | -1.3 | -0.7 | 0.3 | 0.6 | 0.0 |
| March | | | 0.3 | -0.3 | | -0.7 | -1.9 | 0.5 | 0.2 | 0.4 |
| April | | -2.7 | 0.6 | -0.6 | | -1.1 | -2.0 | 0.5 | -1.4 | -0.4 |
| May | | | 0.5 | 1.0 | | -0.5 | | 0.4 | -1.0 | 1.0 |
| June | | | 1.3 | -0.5 | | -0.9 | | 0.2 | -0.6 | 2.0 |

b.

| Time of the day | Cya | Cla | Cop | Dia | Egg | Nau | Pol | Det | Rot | Zoe |
|---|---|---|---|---|---|---|---|---|---|---|
| 09:00 | 1.1 | -0.6 | 0.9 | -0.4 | 1.0 | -0.9 | -1.1 | 0.2 | -0.7 | -0.4 |
| 12:00 | -1.3 | -1.2 | 0.5 | -0.3 | | -0.8 | -1.4 | 0.4 | -0.8 | 0.9 |
| 15:00 | -2.7 | -1.3 | 0.9 | -0.1 | 0.3 | -0.7 | -0.8 | 0.3 | -0.6 | 0.7 |
| 18:00 | -2.4 | | 0.6 | -0.2 | 0.6 | -0.9 | -1.8 | 0.2 | 0.4 | -0.3 |
| 21:00 | -1.3 | | 0.3 | -0.2 | | -1.3 | -1.5 | 0.4 | 0.5 | -0.2 |
| 00:00 | -1.1 | | 0.4 | 0.0 | | -1.2 | -0.7 | 0.5 | -0.9 | -0.2 |
| 03:00 | -1.3 | | 0.4 | 0.1 | | -0.7 | -1.4 | 0.4 | -0.9 | 0.4 |
| 06:00 | -1.2 | -0.5 | 1.1 | -0.6 | | -0.7 | -1.1 | 0.4 | -0.7 | 1.5 |

## TABLE 2

**Shorigin's feeding selectivity index by weight (mg/l) of *Anchovia clupeoides* at different times of the year and the day. There are data only for the last 7 months of study.**

| Month | Sieve size (μm) | | | Time of the day | Sieve size (μm) | | |
|---|---|---|---|---|---|---|---|
| | 63 | 125 | 250 | | 63 | 125 | 250 |
| December | -0.3 | 0.1 | 0.2 | 09:00 | -1.2 | -0.9 | 0.6 |
| January | -0.7 | 0.0 | 0.8 | 12:00 | -0.9 | -0.4 | 0.7 |
| February | -1.2 | -0.5 | 0.7 | 15:00 | -0.8 | -0.3 | 0.7 |
| March | -0.9 | -0.3 | 0.6 | 18:00 | -0.9 | 0.0 | 0.7 |
| April | -1.2 | -0.5 | 0.8 | 21:00 | -0.8 | -0.2 | 0.6 |
| May | -0.7 | -0.4 | 0.6 | 00:00 | -0.6 | -0.2 | 0.6 |
| June | -1.1 | -0.4 | 0.7 | 03:00 | -0.5 | -0.1 | 0.4 |
| | | | | 06:00 | -0.5 | 0.0 | 0.5 |

involved. Whitfield (1980) reported that fishes are able to digest bacteria and fungi associated with the detritus, suggesting that detritus may enhance the nutritional quality of their diets.

Evidence that engraulids prey directly on primary producers may help to better explain the high productivity of this family in general (Blaxter and Hunter 1989), although *A. clupeoides* is typically thought to be a secondary consumer in the CGSM. On the other hand, Hobson (1968) reported that engraulids are capable of efficient feeding during the night and that the visual acuity of both predator and prey may be largely underestimated. We believe that *A. clupeoides* feeds by active hunting regardless of the season and time of day.

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# Gulf and Caribbean Research

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Diet of Tripletail, *Lobotes surinamensis*, from Mississippi Coastal Waters

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# DIET OF TRIPLETAIL, *LOBOTES SURINAMENSIS*, FROM MISSISSIPPI COASTAL WATERS

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*ABSTRACT* The diet of tripletail, *Lobotes surinamensis*, collected from the Mississippi Sound and Mississippi's offshore waters of the Gulf of Mexico between April and September 1995–1997, was investigated through analysis of stomach contents. Of 178 tripletail stomachs examined, 136 (76%) contained prey items, and 42 (24%) were empty. Tripletail with prey in their stomachs ranged from 183 to 787 mm total length (mean 522.6 mm) and 0.14 to 10.5 kg total weight (mean 3.64 kg). The diet consisted of 32 different prey types and was comprised of shrimp, crabs, and teleost fishes which were represented by about equal number and volume of prey but differed in relative importance to the diet, with fishes having greater importance. Principal contributors to the diet were *Farfantepenaeus aztecus*, *Callinectes sapidus*, *Brevoortia patronus*, and *Chloroscombrus chrysurus*. The variety of prey in the diet suggested that tripletail fed opportunistically.

## INTRODUCTION

The tripletail, *Lobotes surinamensis,* is a pelagic fish that occurs in tropical and subtropical oceans, with the exception of the eastern Pacific (Fischer 1978). In the western Atlantic, *L. surinamensis* is distributed from Massachusetts southward to Argentina, including the Gulf of Mexico (Gulf) and the Caribbean Sea (Robins and Ray 1986). *Lobotes surinamensis* is the only member of the percoid family Lobotidae in the Gulf and is a highly esteemed food fish throughout its range (Hoese and Moore 1998).

This species occurs from April through October in offshore Gulf waters, sounds, and estuaries, where it supports a recreational fishery (Benson 1982) and appears in greatest concentration along the Mississippi coast in summer (Baughman 1941). Tripletail often associate with channel markers, wrecks, flotsam, and *Sargassum* algae (Gudger 1931, Hughes 1937, Dooley 1972) and often float aimlessly on their side in surface waters, mimicking drifting debris (Baughman 1943, Breder 1949). Although the biology and life history aspects of *L. surinamensis* from the northern Gulf were studied by Modde and Ross (1981), Ditty and Shaw (1994), Franks et al. (2001), and Brown-Peterson and Franks (2001), the ecology of this species in the Gulf is not well known.

Other than studies by Baughman (1941, 1944), who observed that *L. surinamensis* in Texas waters fed on *Callinectes* spp., there are no published accounts of diet and feeding habits of *L. surinamensis* from Gulf waters. The objective of this study was to describe the diet of *L. surinamensis* from Mississippi coastal waters.

## MATERIALS AND METHODS

### Field procedures

Tripletail used in this study were caught in the recreational hook-and-line fishery from the Mississippi Sound and waters near the offshore barrier islands (Figure 1) between April and September 1995–1997. All fish were caught during daylight hours, and anglers packed their catch in ice immediately following capture. Specimens were sampled opportunistically at dockside and during sport fishing tournaments. The date, time, location of catch, total length (TL, mm), total weight (TW, kg), and sex were recorded for all specimens. Stomachs were removed, placed in labeled plastic bags, and immediately covered with ice for transport to the laboratory, where they were frozen for later examination.

### Laboratory procedures

Stomachs were thawed and opened, and contents were placed onto a 0.840-mm mesh screen sieve and gently washed with fresh water. Prey were sorted and identified to the lowest possible taxonomic level, counted, and measured volumetrically to the nearest 0.1 ml by water displacement in a graduated cylinder. Prey too digested for unequivocal identification were recorded as "remains" and assigned to the appropriate prey category. *Sargassum*, small molluscan shells, and insect parts found in some stomachs were considered non-food items probably ingested incidentally during normal feeding and were not used in our description of the diet.
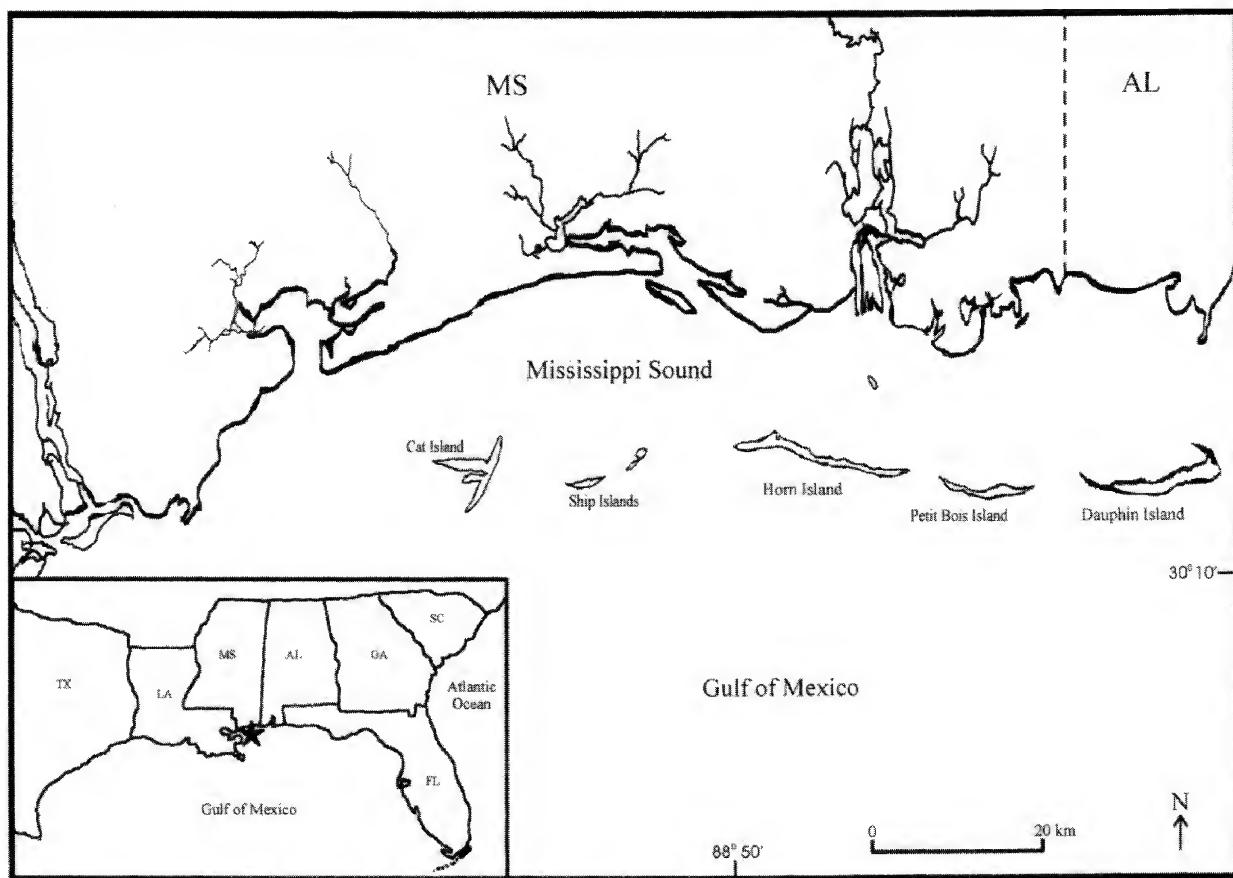
**Figure 1. Map of the study area located off Mississippi.**

## Diet analysis

Diet composition was categorized as percent numeric abundance (%N), percent of total volume (%V) and percent frequency of occurrence (%F) (Hyslop 1980). These dietary metrics were combined to assess overall prey importance for *L. surinamensis* with the Index of Relative Importance (IRI) (Pinkas 1971), where the importance of an item is directly related to the size of the value: IRI = (%N + %V) x %F. The IRI also was expressed as a percentage (%IRI) (Cortés 1997). Stomach contents for the entire sample were pooled for the above computations. Empty stomachs were excluded from computations.

## RESULTS

One hundred thirty six *L. surinamensis* stomachs contained prey (76%), and 42 (24%) were empty. Triptail with prey in their stomachs ranged from 183 to 787 mm TL ($\bar{x}$ = 522.6 mm) and 0.14 to 10.5 kg TW ($\bar{x}$ = 3.64 kg). Crustaceans (shrimp and crabs) and fishes occurred in 72.2% and 65.4% of the stomachs, respectively (Figure 2). Thirty-two prey types were identified, 22 to genus or species level (Table 1).

Crustaceans and fishes in the diet were almost equal in total number of prey (50.3% and 49.7%, respectively) and total prey volume (49.4% and 50.6%, respectively) but differed substantially in %IRI contribution to the diet (38.6 and 61.4, respectively) (Figure 2).

Shrimp contributed 18.5%N, 33.4%V, 48.6%F and 25.7%IRI to the diet. As a group, penaeid shrimp (*Farfantepenaeus aztecus, Farfantepenaeus* sp., *Litopenaeus setiferus, Trachypenaeus similis*, and unidentified penaeids) accounted for 16.2%N, 31.5%V and 25.3%IRI of the overall diet (Table 1). Among crustaceans, *F. aztecus* was the dominant prey and most frequently (20.6%F) identified prey item in the diet. *Farfantepenaeus aztecus* ranked second in importance numerically (5.9%) among crustaceans, and ranked second in volumetric importance (16.7%) and %IRI (15.8) among all prey consumed (Table 1). Other identifiable penaeid shrimp (*L. setiferus* and *Farfantepenaeus* sp.), unidentifiable penaeids, and shrimp remains (all pooled) occurred more frequently and in greater abundance (12.4%N) than did *F. aztecus*.

Crabs contributed 31.8%N, 16.0%V, 41.2%F and 12.9%IRI to the diet. Identifiable crabs were members
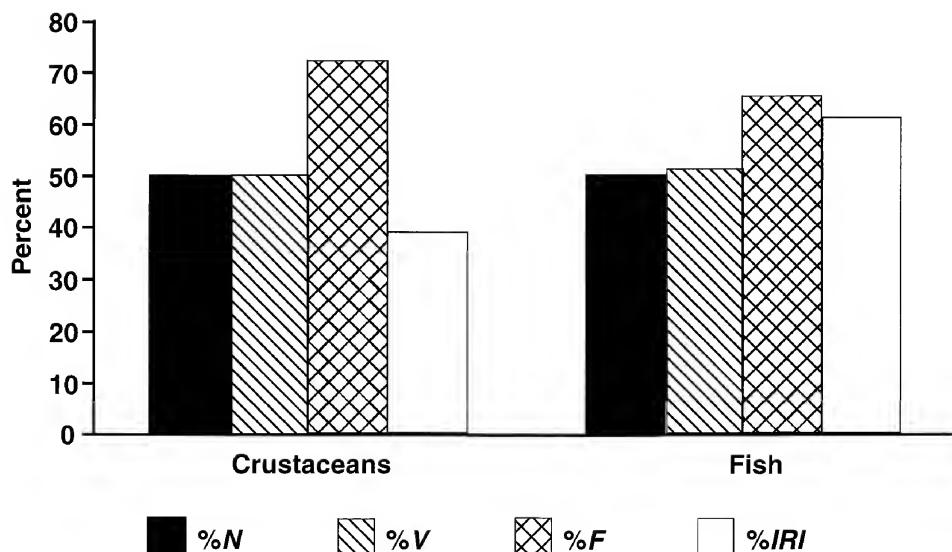
Figure 2. Percent numerical abundance (%N), percent total volume (%V), percent frequency of occurrence (%F) and percent index of relative importance (%IRI) for principal prey categories in the diet of *Lobotes surinamensis* from the northcentral Gulf of Mexico.

of the family Portunidae and included *Callinectes sapidus*, *C. similis*, *Portunus gibbesii*, *P. sayi*, *P.* spp. and other specimens which could be identified only to family level (Table 1). *Callinectes sapidus* was the most important crab prey consumed (Table 1) and, in terms of numerical abundance, was the predominant crustacean in the diet (8.9%N). *Callinectes similis*, *P. gibbessi*, *P. sayi*, *Portunus* spp. and unidentified portunids were all consumed in similar numbers.

The relative importance of the fish group (61.1%IRI) was more than twice that of shrimp (25.7%IRI) and almost five times greater than crabs (12.9%IRI). Fish prey were represented by 12 species plus *Anchoa* spp., Clupeidae, Carangidae, Blenniidae, Bothidae, and Soleidae. In terms of relative importance, *Brevoortia patronus* was the most important identifiable fish consumed (12.4%IRI) and the second most important item among all identifiable prey. Of total prey consumed, *Chloroscombrus chrysurus* was the most abundant identifiable prey (16.9%N) and the third most important identifiable prey based upon %IRI (7.4). *Anchoa* spp. occurred in only three stomachs (2.2%F) but ranked third, numerically, among identifiable fish.

Fish remains (unidentifiable fish taxa) dominated the diet on the basis of numeric importance (18.4%N), frequency occurrence (41.9%F) and %IRI (40.6) and ranked third in volumetric contribution (10.1%V). Fish of lesser contribution to the diet were *Bascanichthys bascanium*, *Myrophis punctatus*, *Porichthys plectrodon*, *Menidia beryllina*, *Selar crumenophthalmus*, *Lagodon*

*rhomboides*, *Chaetodipterus faber*, *Hypsoblennius hentzi*, *Peprilus alepidotus*, *Peprilus burti*, *Anchoa* sp., and unidentified members of families Clupeidae, Carangidae, Blennidae, Bothidae, and Soleidae.

## DISCUSSION

The diversity of crustaceans and fishes in the diet reflected opportunistic feeding by *L. surinamensis* on a variety of regionally abundant prey in the northcentral Gulf. Although most fishes consumed by tripletail were infrequently encountered and represented by few specimens, our findings that the overall relative importance of teleost prey to the diet of tripletail was greater than shrimp and crabs were consistent with those of Merriner and Foster (1974) off North Carolina. In terms of relative importance, *B. patronus*, *Anchoa* spp., and *C. chrysurus* were the dominant identifiable piscine prey in our study. Merriner and Foster (1974) reported that *Opisthonema oglinum* and *Brevoortia tyrannus* were of greater importance to the diet than other teleost or crustacean prey.

Among crustaceans, *F. aztecus* and portunid crabs, particularly *C. sapidus*, were more important in this study than reported by Merriner and Foster (1974). Squid were found in stomachs of North Carolina tripletail (Merriner and Foster 1974) but were not encountered during our study. We observed no major prey items from inshore tripletail that were not present in stomachs from Gulf specimens (n = 7). Unfortunately,

## TABLE 1

Diet composition of tripletail, *Lobotes surinamensis*, from Mississippi coastal waters, 1995–1997. Percent frequency of occurrence is based on stomachs containing food (*n* = 136). Unid. = unidentified. Total stomachs analyzed = 178; No. (%) containing prey = 136 (76%); No. (%) empty = 42 (24%); T = trace amount (< 0.1).

| Prey | Number of Individual prey items | Percent Number | Volume (mL) | Percent Volume | Percent Frequency Occurrence | Index of Relative Importance (IRI) | Percent IRI |
|---|---|---|---|---|---|---|---|
| **Class Crustacea** | | | | | | | |
| *Farfantepenaeus aztecus* | 35 | 5.9 | 312.6 | 16.7 | 20.6 | 465.6 | 15.8 |
| *Litopenaeus setiferus* | 17 | 2.8 | 127.1 | 6.8 | 10.3 | 98.9 | 3.4 |
| *Farfantepenaeus* sp. | 23 | 3.9 | 115.5 | 6.2 | 14.0 | 141.4 | 4.8 |
| *Trachypenaeus similis* | 1 | 0.2 | 0.1 | T | 0.8 | 0.2 | T |
| Unid. penaeid | 20 | 3.4 | 34.3 | 1.8 | 7.4 | 38.5 | 1.3 |
| Shrimp remains | 14 | 2.3 | 36.1 | 1.9 | 2.9 | 12.9 | 0.4 |
| *Callinectes sapidus* | 53 | 8.9 | 103.9 | 5.6 | 9.6 | 139.2 | 4.7 |
| *Callinectes similis* | 27 | 4.5 | 68.0 | 3.6 | 8.1 | 65.6 | 2.2 |
| *Portunus gibbesii* | 17 | 2.8 | 25.0 | 1.3 | 3.7 | 15.2 | 0.5 |
| *Portunus sayi* | 24 | 4.0 | 17.8 | 1.0 | 3.7 | 18.5 | 0.6 |
| *Portunus* spp. | 29 | 4.9 | 19.7 | 1.1 | 5.9 | 35.4 | 1.2 |
| Unid. portunid | 16 | 2.7 | 34.7 | 1.9 | 9.6 | 44.2 | 1.5 |
| Crab remains | 24 | 4.0 | 28.6 | 1.5 | 11.8 | 64.9 | 2.2 |
| | | | | | | | |
| **Class Osteichthyes** | | | | | | | |
| *Bascanichthys bascanium* | 1 | 0.2 | 33.0 | 1.8 | 0.7 | 1.4 | T |
| *Myrophis punctatus* | 1 | 0.2 | 11.0 | 0.6 | 0.7 | 0.6 | T |
| *Brevoortia patronus* | 34 | 5.7 | 472.8 | 25.3 | 11.8 | 365.8 | 12.4 |
| Unid. clupeid | 1 | 0.2 | 30.0 | 1.6 | 0.7 | 1.3 | T |
| *Anchoa* spp. | 26 | 4.3 | 6.7 | 0.4 | 2.2 | 10.3 | 0.4 |
| *Porichthys plectrodon* | 1 | 0.2 | 0.5 | T | 0.7 | 0.1 | T |
| *Menidia beryllina* | 4 | 0.7 | 9.5 | 0.6 | 1.5 | 2.0 | 0.1 |
| *Chloroscombrus chrysurus* | 101 | 16.9 | 79.0 | 4.2 | 10.3 | 217.3 | 7.4 |
| *Selar crumenophthalmus* | 1 | 0.2 | 50.0 | 2.7 | 0.7 | 2.0 | 0.1 |
| Unid. carangid | 1 | 0.2 | 0.5 | T | 0.7 | 0.1 | T |
| *Lagodon rhomboides* | 2 | 0.3 | 11.2 | 0.6 | 1.5 | 1.4 | T |
| *Chaetodipterus faber* | 1 | 0.2 | 6.0 | 0.3 | 0.7 | 0.4 | T |
| *Hypsoblennius hentzi* | 1 | 0.2 | 3.5 | 0.2 | 0.7 | 0.3 | T |
| Unid. blenniid | 5 | 0.8 | 1.4 | 0.1 | 0.7 | 0.6 | T |
| *Peprilus alepidotus* | 2 | 0.3 | 32.0 | 1.7 | 0.7 | 1.4 | 0.1 |
| *Peprilus burti* | 2 | 0.3 | 2.0 | 0.1 | 0.7 | 0.3 | T |
| Unid. bothid | 1 | 0.2 | 2.0 | 0.1 | 0.7 | 0.2 | T |
| Unid. soleid | 1 | 0.2 | 3.0 | 0.2 | 0.7 | 0.3 | T |
| Fish remains | 110 | 18.4 | 189.6 | 10.1 | 41.9 | 1,194.2 | 40.6 |
| **Total** | **596** | | **1,867.1** | | | **2,940.5** | |

we were not able to examine ontogenetic diet patterns due to small sample sizes.

Our sample consisted of tripletail caught exclusively with hook-and-line gear; therefore, most of the fish we examined were probably actively feeding at the time of capture. We could not determine whether the large number of fish with empty stomachs was related to lack of feeding or to regurgitation.

We have observed that captive tripletail consume food by suction-feeding, a method of feeding previously reported for tripletail by Breder (1925) and other species (Lauder 1983, Liem 1993, Luczkovich et al. 1995). Although tripletail have sharp incisors on upper and lower jaws, most identifiable prey in our study were consumed whole, suggesting that suction-feeding is used by tripletail when they drift as camouflaged predators within *Sargassum* mats and when floating under debris.

The diversity of prey consumed by tripletail suggests that their foraging behavior is versatile. For example, anchovies, clupeids, carangids, and stromateids are important components of the open-water ichthyofauna, whereas portunid crabs are both nektonic and benthic. Furthermore, shrimps, eels, and blennies are predominantly benthic inhabitants, and bothids and soleids are demersal.

This study represents the first account of the diet of *L. surinamensis* from the northern Gulf. Knowledge of tripletail diet is necessary to develop a better understanding of the life history requirements and trophic ecology of this species.

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# The Biology of Wahoo (*Acanthocybium solandri*) in the Western Central Atlantic

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# THE BIOLOGY OF WAHOO *(ACANTHOCYBIUM SOLANDRI)* IN THE WESTERN CENTRAL ATLANTIC

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*ABSTRACT* This contribution summarizes aspects of the biology of the wahoo, *Acanthocybium solandri* (Scombridae), that are pertinent to assessment and management of this species in the western central Atlantic (WCA). In this region wahoo is a target species for both commercial and recreational fisheries, and annual landings appear to have increased steadily over the last 30 years to in excess of 2000 mt. Wahoo is believed to be migratory, but little is known of the migration patterns. Significant seasonal variation in catches within the region indicates that it is seasonally abundant in most locations. Periods of peak abundance occur from the fall through spring in the southeastern and northern Caribbean islands, and are restricted to the warmer months (late spring through early fall) in the more northerly locations (northern Gulf of Mexico, North Carolina, and Bermuda). Wahoo exhibits early sexual maturity (within the first year) and a spawning season that extends from at least May to October. Females are multiple batch spawners and are highly fecund. Limited age and growth studies indicate that it is a relatively fast-growing species, has high mortality, and probably lives for 5–6 years. Wahoo is primarily piscivorous, although some invertebrates including squids are eaten. A relatively small number of parasite species have been associated with it. There is no evidence of more than a single shared stock of wahoo in the WCA, and recent genetic studies, using RAPD markers, suggest that stock boundaries may extend beyond this region. The status of the wahoo resource in the WCA remains unclear. Reliable wahoo catch and fishing effort data from the entire WCA, improved knowledge of migration patterns, reproductive characteristics and critical habitat (e.g., preferred spawning areas), validation of age, growth and mortality estimates, and a more comprehensive analysis of stock structure for the entire Atlantic are needed for informed wahoo stock assessment and management.

## INTRODUCTION

The wahoo, *Acanthocybium solandri* Cuvier, is classified in the family Scombridae. Johnson (1986) postulated that this species may be more closely related to the billfishes. However, a recent molecular study (Finnerty and Block 1995) confirms that wahoo is a scombrid, not an istiophorid, being closely related to the Spanish mackerels (Collette 1999, Collette et al. 2001).

Wahoo is a slender, streamlined, oceanic, epipelagic fish and is important to commercial and recreational fisheries throughout the western central Atlantic (WCA) (e.g., Goodson 1976, Collette 1978, in press, Mahon 1993, SAFMC 2000). Despite its importance to fisheries, wahoo remains unmanaged. Furthermore, the biological information needed to support management of this species is somewhat sparse and is scattered throughout the published and unpublished literature. In this paper we attempt to compile and review the biological information available for wahoo that is relevant to assessment and management of this species, at a time of increasing interest in addressing the management of shared pelagic stocks in this region (e.g., SAFMC 2000, CFRAMP 2001, FAO 2002a).

## DISTRIBUTION, EXPLOITATION AND SEASONALITY

The wahoo has a circum-tropical distribution, occupying tropical and subtropical waters of the Atlantic (including the Mediterranean and Caribbean seas), Pacific and Indian oceans (Collette and Nauen 1983), and extending seasonally into temperate waters (Hogarth 1976). In the WCA, wahoo occurs from as far south as the northeast coast of Brazil (see Robins and Ray 1986) to as far north as Rhode Island in the USA (see Goodyear 1999 cited in SAFMC 2000). Wahoo is reported to be present year-round throughout much of the Caribbean and Gulf of Mexico, although its abundance, or availability to the fisheries, appears to have a seasonal pattern in most places (Table 1). Further north, in the Atlantic (off North Carolina and Bermuda), some wahoo appear to be present year-round, but abundance is highly seasonal, with the fish being far more abundant in the warmer months (Table 1).

Wahoo is caught by recreational and commercial fisheries in South America off Venezuela (Cervigón 1994) and in large numbers by commercial longliners off Brazil and the Netherlands Antilles in the southern Caribbean (ICCAT 2001, 2002, FAO 2002b). It is a target species of commercially important artisanal pe-

**TABLE 1**

Locations and approximate seasonality of highest catches of recreational and commercial fisheries for wahoo in the western central Atlantic.

| Area | Location | Highest catches | Selected references |
|---|---|---|---|
| South America | | ? | FAO 2002b<br>Cervigón 1994<br>ICCAT 2001, 2002 |
| Southern Caribbean | | ? | ICCAT 2002 |
| Southeastern Caribbean | | Late fall–early summer | Mahon et al. 1982, 1990<br>Mahon 1993<br>George et al. 2001 |
| Northern Caribbean | US Virgin Islands | Sep–Mar | Brandon 1987 |
| | Puerto Rico | Sep–Mar | SAFMC 1998 |
| | Jamaica | Feb–May | Harvey 1988 |
| | Cuba | Winter | Rivas 1951 |
| | Bahamas | Fall–Winter | Franks et al. 2000 |
| Northern Gulf of Mexico | | Spring–Fall | Goodyear 1999 (in SAFMC 2000)<br><br>Franks et al. 2000 |
| Eastern USA | | Jul–Aug | Hogarth 1976<br>Manooch and Laws 1979<br>Manooch et al. 1981<br>Goodyear 1999 (in SAFMC 2000) |
| Atlantic | Bermuda | Apr–Sep | Luckhurst and Trott 2000 |

lagic fisheries throughout the southeastern Caribbean islands of Grenada (Finlay and Rennie 1988), Barbados (Mahon et al. 1982), St. Lucia (Murray and St. Marthe 1991, Gobert and Domalain 1995), Dominica (Guiste et al. 1996), Martinique (Guillou and Lagin 2000), and Guadeloupe (Reynal et al. 1999). Although it is landed year-round in the southeastern Caribbean, catch rates for "kingfish" (an aggregate group composed primarily of wahoo and a small proportion of king mackerel) are lowest during the summer months (July–September) and show several low modes from November through June (e.g., Hunte 1987, Mahon et al. 1990, OECS 1996, George et al. 2001).

In the northern Caribbean, wahoo is caught by recreational and commercial artisanal fishers off the Cayman Islands (Barnes 1972 cited in Hogarth 1976), Jamaica (Aiken 1993, Mahon 1995, Harvey 1988), the northwest coast of Cuba (Rivas 1951, Collette 1978), the Dominican Republic (Brown 2001), Puerto Rico (Centaur Assoc. 1983), the US Virgin Islands (Hogarth 1976, Olsen and Wood 1983, Centaur Assoc. 1983, Brandon 1987), and the Bahamas (Hogarth 1976, Franks

et al. 2000). In general, highest catches in this region occur from the fall through early spring (Table 1), although Harvey (1988) noted that peak wahoo catches in Jamaica occur from February to May.

Wahoo is important to commercial and recreational fisheries in the northern Gulf of Mexico (Texas, Louisiana, Mississippi, Alabama, and western Florida), the Atlantic from the Florida Straits to North Carolina (Hogarth 1976, Goodyear 1999 cited in SAFMC 2000), and Bermuda (Luckhurst and Ward 1996, Smith-Vaniz et al. 1999). In the northern Gulf of Mexico, wahoo is caught year-round, although they are apparently more abundant during spring through fall (Franks et al. 2000). In the Atlantic, wahoo are reported off the east coast of Florida year-round and further north off South Carolina during the spring and summer (SAFMC 1998). Off North Carolina, there is some evidence that wahoo may be present in the Gulf Stream year-round, although they are only considered to be abundant from late July through August (Hogarth 1976, Manooch and Laws 1979, Manooch et al. 1981). In Bermuda, wahoo is taken year-round, but catches have a strong seasonal pattern

with 60–70% of the annual landings consistently occurring in the second and third quarters of the year (April–September) (Luckhurst and Trott 2000). Historically, there are spring (April–May) and fall (August–September) runs of wahoo in Bermuda which vary inter-annually in magnitude and to a lesser degree in timing (Luckhurst and Trott 2000). Wahoo landings are consistently lowest (5–8% of annual landings) in the first quarter which coincides with the lowest water temperatures (18–19°C) as well as reduced fishing effort.

Estimated annual landings of wahoo in the WCA are reported collaboratively by ICCAT and FAO, although slight differences are often found between the two data sets as a result of differences in the timing of required reporting and revisions (FAO 2002b). Records show a steady and rapid increase in wahoo landings from around 400 mt in the mid to late 1970s to an mean of 1,854 mt over the last three years for which there are data (1998–2000; Table 2). However, at least part of this increase is likely to represent an increase in reporting to ICCAT, rather than an actual increase in landings. For example, wahoo landings are shown from Grenada only since 1978, Barbados since 1979, USA since 1985, St. Vincent since 1988, Dominica and St. Lucia since 1990, and Trinidad and Tobago since 1991, although the fisheries in most of these countries have been taking wahoo for much longer periods of time. Wahoo catches are almost certainly under reported across the WCA. Many countries known to be taking wahoo, even if only in relatively small quantities, are not listed in the ICCAT (nor FAO) data records, while others have landings that are under reported (e.g., landings for US Gulf of Mexico and Atlantic coasts for 1984–1992 are far higher than reported in the ICCAT database (see Tables 2 and 3). One problem is that wahoo are aggregated with king mackerel (*Scomberomorus cavalla*) in national landings data of several countries (e.g., Hunte 1987, Mahon 1993) and cannot, therefore, be disaggregated into separate species in the ICCAT and FAO databases. Furthermore, statistics reported in the databases are biased by a country's capacity and willingness to accurately collect, process, and report fisheries data (FAO 2002a). Although recreational catches are likely to be quite substantial and often greatly exceed commercial landings (e.g., in the US Gulf, south Atlantic, and mid-Atlantic states: Goodyear 1999 cited in SAFMC 2000; in the US Virgin Islands: Brandon 1987), they frequently go unreported in this region (e.g., Franks et al. 2000, Luckhurst and Trott 2000). Garber et al. (2001) note with concern that increased recreational fishing in the US and Caribbean waters is putting additional harvest pressure on this species.

Wahoo landings have shown a slow but steady increase in many southeastern Caribbean countries from the 1970s through the 1980s (Mahon 1996), and particularly in St. Lucia from the mid 1990s (George et al. 2001). This reflects an increase in the number and fishing power of vessels and fishers (George et al. 2001). The US National Marine Fisheries Service (NMFS) records (1984–1997) reported by Goodyear (1999 cited in SAFMC 2000) indicate that wahoo landings in the US Gulf of Mexico have increased considerably since the mid 1980s, but show marked inter-annual variation (Table 3). These records also indicate a gradual increase in the commercial and recreational landings of wahoo for the US south Atlantic states (with the exception of an anomalously high year for the recreational fishery in 1986) (Table 3). In Bermuda, landings of wahoo have increased steadily over the 24 year (1975–1997) time-series, reflecting an increase in pelagic fishing effort and improvements to gear and fishing techniques over this time period (Luckhurst and Trott 2000).

## Movements and Migration

Little is known about the movements or migration patterns of wahoo in the WCA, although it is generally agreed (based on seasonality of landings by commercial and recreational fisheries) that they move seasonally, extending into cooler waters in the warmer months, and are migratory within and beyond the Exclusive Economic Zones (EEZs) of countries within the WCA region. Wahoo congregate in the vicinity of drifting objects including *sargassum* (e.g., NMFS 1997), and fishers have learned to rely heavily on these natural moving fish attracting devices (FADs) to catch wahoo and other large pelagics (e.g., Taquet 1998, Gomes et al. 1998, George et al. 2001). Wahoo are also caught around anchored FADs off Martinique and Guadeloupe (Laurans et al. 1999, Reynal et al. 1999).

There are a few on-going conventional tagging programs for wahoo in the WCA. A CFRAMP tagging program for large pelagic species commenced in 1996 (Singh-Renton 2001). To date, a total of 249 wahoo have been tagged in southeastern Caribbean waters, but no recaptures have been reported (Singh-Renton, pers. comm.). In Bermuda, a wahoo tagging program commenced in 1998 (Nash et al. 2002). To date, only 15 wahoo have been tagged and released. A single wahoo recaptured 10 months later, 64 km away from the point of release, may have remained in Bermuda waters during its liberty or returned there after a seasonal

## TABLE 2

### Estimated annual wahoo landings (mt) for countries within the western central Atlantic (data from ICCAT 2002).

| Place | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Antigua | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Aruba | 100 | 100 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 120 | 90 | 80 | 80 | 70 | 60 | 50 | 50 | 125 | 40 | 50 | 50 | 50 | 50 | 50 |
| Barbados | 0 | 0 | 0 | 189 | 116 | 144 | 219 | 222 | 219 | 120 | 138 | 159 | 332 | 51 | 51 | 60 | 51 | 91 | 82 | 42 | 35 | 52 | 52 | 41 | 41 |
| Brazil | 9 | 3 | 6 | 69 | 1 | 1 | 0 | 0 | 0 | 21 | 141 | 133 | 58 | 92 | 52 | 64 | 71 | 33 | 28 | 1 | 16 | 58 | 40 | 0 | 0 |
| Dominica | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 38 | 43 | 59 | 59 | 59 | 58 | 58 | 58 | 58 | 50 | 50 |
| Dominican Rep. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 6 | 9 | 13 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Grenada | 0 | 0 | 35 | 31 | 25 | 23 | 41 | 94 | 50 | 51 | 82 | 54 | 137 | 57 | 54 | 77 | 104 | 96 | 46 | 49 | 56 | 54 | 54 | 82 | 82 |
| Netherland Ant. | 178 | 178 | 215 | 215 | 215 | 215 | 215 | 215 | 215 | 245 | 250 | 260 | 280 | 280 | 280 | 250 | 280 | 270 | 250 | 230 | 230 | 230 | 230 | 230 | 230 |
| St. Lucia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 77 | 79 | 150 | 141 | 96 | 80 | 221 | 223 | 223 | 310 | 310 |
| St. Vincent | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 28 | 33 | 33 | 41 | 28 | 16 | 23 | 10 | 10 | 52 | 52 |
| Trinidad & Tobago | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 118 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 2 |
| USA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13 | 12 | 57 | 128 | 110 | 82 | 134 | 203 | 827 | 391 | 764 | 608 | 750 | 614 | 857 | 640 |
| Bermuda | 20 | 35 | 23 | 33 | 46 | 24 | 40 | 49 | 46 | 46 | 65 | 43 | 61 | 63 | 74 | 67 | 60 | 58 | 50 | 93 | 99 | 105 | 108 | 104 | 51 |
| Venezuela | 67 | 71 | 54 | 100 | 57 | 77 | 175 | 66 | 125 | 147 | 113 | 106 | 141 | 101 | 159 | 302 | 333 | 514 | 542 | 540 | 487 | 488 | 360 | 467 | 4 |
| Totals | 374 | 387 | 448 | 752 | 575 | 599 | 805 | 761 | 770 | 758 | 921 | 902 | 1222 | 841 | 971 | 1,296 | 1,408 | 2,187 | 1,697 | 1,913 | 1,883 | 2,079 | 1,800 | 2,244 | 1,512 |

## TABLE 3

**Recreational and commercial landings of wahoo (mt) from the US Gulf of Mexico and Atlantic coast states for the years 1984–1997. Data are from the US NMFS as presented by Goodyear (1999, cited in SAFMC 2000).**

| Year | Gulf of Mexico | | South Atlantic | | Mid-Atlantic | | New England | | Total |
|------|------|------|------|------|------|------|------|------|-------|
| | Rec. | Com. | Rec. | Com. | Rec. | Com. | Rec. | Com. | |
| 1984 | 9.1 | 2.4 | 187.7 | 11.4 | 0.0 | 0.0 | 0.0 | 0.0 | 210.6 |
| 1985 | 55.0 | 4.9 | 191.9 | 12.9 | 6.6 | 0.1 | 0.0 | 0.0 | 271.4 |
| 1986 | 92.0 | 11.0 | 1120.4 | 12.1 | 23.7 | 0.1 | 0.0 | 0.5 | 1259.8 |
| 1987 | 169.0 | 41.0 | 361.5 | 23.3 | 6.0 | 0.2 | 0.0 | 0.0 | 601.0 |
| 1988 | 198.4 | 103.4 | 378.0 | 23.7 | 0.0 | 0.5 | 0.0 | 0.0 | 704.0 |
| 1989 | 30.0 | 109.4 | 321.4 | 19.9 | 11.4 | 0.4 | 0.0 | 0.0 | 492.5 |
| 1990 | 67.6 | 51.2 | 195.1 | 26.4 | 0.0 | 0.8 | 0.0 | 0.0 | 341.1 |
| 1991 | 206.9 | 84.9 | 241.7 | 28.3 | 1.0 | 0.4 | 0.0 | 0.0 | 563.2 |
| 1992 | 157.5 | 134.0 | 292.3 | 29.4 | 0.0 | 0.9 | 0.0 | 0.5 | 614.6 |
| 1993 | 257.1 | 116.7 | 286.9 | 33.6 | 0.0 | 1.3 | 2.6 | 0.0 | 698.2 |
| 1994 | 61.0 | 71.0 | 350.5 | 30.6 | 18.9 | 1.7 | 0.0 | 7.6 | 541.3 |
| 1995 | 187.2 | 65.4 | 439.8 | 46.4 | 5.2 | 3.2 | 0.0 | 0.0 | 747.2 |
| 1996 | 148.6 | 65.8 | 384.8 | 36.2 | 5.4 | 1.1 | 0.0 | 0.1 | 642.0 |
| 1997 | 213.1 | 73.6 | 403.7 | 41.5 | 0.0 | 1.1 | 0.0 | 0.0 | 733.0 |

migration. It is possible that it may have followed a stable migratory route in the Atlantic, with the Bermuda Seamount as a seasonal feeding area, as has been postulated for yellowfin tuna (*Thunnus albacares*) and blackfin tuna (*Thunnus atlanticus*) in Bermuda (Luckhurst et al. 2001).

In the southeastern Caribbean, Neilson et al. (1999) suggested that the lack of a modal progression in length-frequency data is consistent with recruitment to the fishing grounds year-round and a highly migratory behavior. However, George et al. (2001) found a gradual increase in monthly mean size of wahoo taken from October through July and then a marked decrease through August to October, suggesting this might be due to migration of the older fish beyond the southeastern Caribbean region at the end of the peak fishing season. Neilson et al. (1999) suggested that the migration model for the southern stock of dolphin, *Coryphaena hippurus*, (wherein it is suggested that the fish move sequentially north through the waters of the Lesser Antilles countries, with a return migration south via the waters further to the east: see Oxenford and Hunte 1986) may also apply to wahoo. However, Hunte (1987) examined seasonality of the catch of "kingfish" (primarily wahoo) from several of the Lesser Antilles islands, and concluded that no clear pattern of movement could be detected. Furthermore, George et al. (2001) report a steady decrease northwards in mean length of wahoo caught around five islands in the southeastern Carib-

bean. This is contrary to the pattern seen in the mean size of dolphin landed up the island chain (Oxenford and Hunte 1986).

In the northern part of the WCA, wahoo is believed to migrate through the Florida Straits and along the Gulf Stream (Rivas 1951). Hogarth (1976) concurred with this when he suggested (based on seasonality of catches) that wahoo migrates northward from Florida waters during the spring with the peak of the migration occurring in late July and early August.

## REPRODUCTIVE BIOLOGY

### Sex ratio

Hogarth (1976) reported a strong female bias for wahoo caught in June through August by the recreational fishery (1964–1972) in North Carolina, with a consistent ratio of 3:1 females to males. He suggested that this skewed sex ratio may be a result of: different migration patterns between the sexes, a greater catchability of females resulting from differences between the sexes in preferred habitat, or a shorter life-span in males such that there are few males in the size range taken by the fishery. Interestingly, a similar female biased sex ratio for dolphin landings is believed to result from inter-sexual differences in attraction to floating objects targeted by fishers (see Oxenford 1999).

## Age and size at maturity

For wahoo from the northern Gulf of Mexico, preliminary estimates by Brown-Peterson et al. (2000) indicated that males reach maturity at one year of age and that 50% maturity is reached at < 935 mm fork length (FL). They also reported that females can reach sexual maturity as small as 850 mm FL but suggested a size of around 975 mm FL or larger for most females, 50% maturity at 1020 mm FL (approximately 2 years old) and 100% maturity at 1050 mm FL. Both males and females from North Carolina reach sexual maturity during their first year of life, at around 860 mm total length (TL) and 3.4 kg total weight for males and 1010 mm TL and 5.4 kg for females (Hogarth 1976). In Bermuda, preliminary data for wahoo suggest that size at maturity is around 1020 mm FL for males, while females are smaller (950 mm FL) (SAFMC 1998).

## Fecundity and egg size

Most of the reproductive parameter estimates are from very small sample sizes and should be treated as preliminary. Examination of oocyte size-frequency data for wahoo from the northern Gulf of Mexico revealed that it is a multiple batch spawner with asynchronous oocyte development, with hydrated oocyte diameters ranging from 700–900 μm (Brown-Peterson et al. 2000). The few estimates of fecundity available vary widely (Table 4). This is in part due to the different definitions of fecundity, with some authors reporting total eggs in mature ovaries (e.g., Hogarth 1976, Collette and Nauen 1983, Collette in press) and others reporting batch and seasonal (annual) fecundity (Brown-Peterson et al. 2000). Mean relative batch fecundity for three wahoo from the northern Gulf of Mexico was estimated at 57.7 eggs per g ovary-free body weight (Brown-Peterson et al. 2000). They noted an apparent increase in batch fecundity with size and age but no increase in the relative fecundity. Spawning frequency per ripe female was also estimated as every two to six days in June, based on histological examinations to determine the percentage of females in the late developing stage with ovaries containing postovulatory follicles. Annual fecundity estimates are based on this spawning frequency being maintained over the four-month spawning season (Table 4). Hogarth (1976) reported a fecundity-length relationship (fecundity = 0.0002 cm TL $^{4.849}$) for 87 females from North Carolina ranging in size from 1030–1800 mm TL (5.8–39.5 kg).

## Gonad maturation, gonadosomatic indices and spawning season

Nine developmental stages of gonad maturation have been described for males and females from the Gulf of Mexico and Bimini, based on macroscopic and histological examination (Brown-Peterson et al. 2000). Four male maturity stages, which are easy to distinguish in the field, and six female stages, which are more difficult to distinguish, have been described for wahoo from North Carolina (Hogarth 1976).

Wahoo has a relatively low gonadosomatic index (GSI) as is typical for medium and large sized oceanic pelagic species (Oxenford 1985). In the northern Gulf of Mexico, the highest GSI value (9.5%) was for a female captured in June, while male GSI values rarely exceed 1.0% (Brown-Peterson et al. 2000). In Bermuda, the maximum GSI value recorded for a female was 5.85% for a fish weighing 24.9 kg and caught in July (Luckhurst unpubl. data).

## TABLE 4

Fecundity estimates for wahoo in the western central Atlantic. [1]Total number of oocytes in mature ovaries, [2]Number of hydrated oocytes in mature ovaries, [3]Estimate of number of oocytes spawned per annual spawning season.

| Location | Parameter | No. eggs | Fish size | N (no. fish) | Reference |
|---|---|---|---|---|---|
| Western central Atlantic | Fecundity[1] | 6,000,000 | 1310 mm | 1 | Collette and Nauen 1983 Collette in press |
| Northern Gulf of Mexico | Mean batch fecundity[2] | 1,146,395 ± 291,210 SE | 1030–1630 mm FL (2–5 kg) | 3 | Brown-Peterson et al. 2000 |
| | Annual fecundity[3] | 30,000,000– 92,800,000 | | | |
| North Carolina | Fecundity[1] | 560,000– 45,340,000 | 1030–1800 mm TL (6.15-39.5 kg) | 87 | Hogarth 1976 |

## TABLE 5

### Spawning seasons for female wahoo in the western central Atlantic.

| Location | Spawning season (peak activity) | Source of data | Reference |
|---|---|---|---|
| Straits of Yucatan | May–October (June) | Larval occurrence | Wollam 1969 |
| Northern Gulf of Mexico | May–August (June) | Gonad analyses | Brown-Peterson et al. 2000 |
| Straits of Florida | May–October (June) | Larval occurrence | Wollam 1969 |
| North Carolina | June–August (June/July) | Gonad analyses | Hogarth 1976 |
| Bermuda | May–August (?) | Gonad analyses | Luckhurst unpubl. |

From relatively limited studies of reproduction, wahoo appears to have an extended summer (May–October) spawning season (Table 5). However, there have been no studies of spawning behavior from the southerly part of its range in the WCA, and evidence is insufficient to determine a preferred spawning environment. Fish larval collections in the WCA indicate that wahoo larvae are widespread in the Caribbean Sea and Gulf of Mexico but have been found only in very small numbers (Wollam 1969, Richards 1984, Richards et al. 1984). Collette and Nauen (1983) reported that wahoo in different maturity stages are frequently caught together and that spawning seems to extend over a long period. Bimini wahoo, sampled only in November, show slightly elevated female GSI values and a wide range of spermatogenic stages in males, suggesting at least some spawning activity during this month and a readiness to continue spawning in one to three months time (Brown-Peterson et al. 2000). Based on very limited larval collections, wahoo from the Straits of Yucatan and Florida have a spawning season extending from

May to October (Wollam 1969). In the northern Gulf of Mexico, Brown-Peterson et al. (2000) noted that only late development through spent stages were found and concluded from monthly GSI values (Figure 1) and from histological examination of gonads that females have a 4-month (May–August) spawning season, with peak spawning in June, while males have a slightly more extended spawning season into September. They also suggested that there may be two temporally different spawning groups of female wahoo, since 10% of females sampled in the peak spawning month (June) had regressed ovaries. In the Gulf Stream off North Carolina, Hogarth (1976) concluded from monthly gonadosomatic indices (Figure 1) and frequency of occurrence of mature, ripe, and spent fish, that wahoo spawns from late June through August with peak activity occurring in June and July. He reported the highest frequency of mature and ripe females in June, a mixture of mature, ripe, and spent females in July and August, and spent females in September and October. He noted that few immature males are caught off North Carolina.
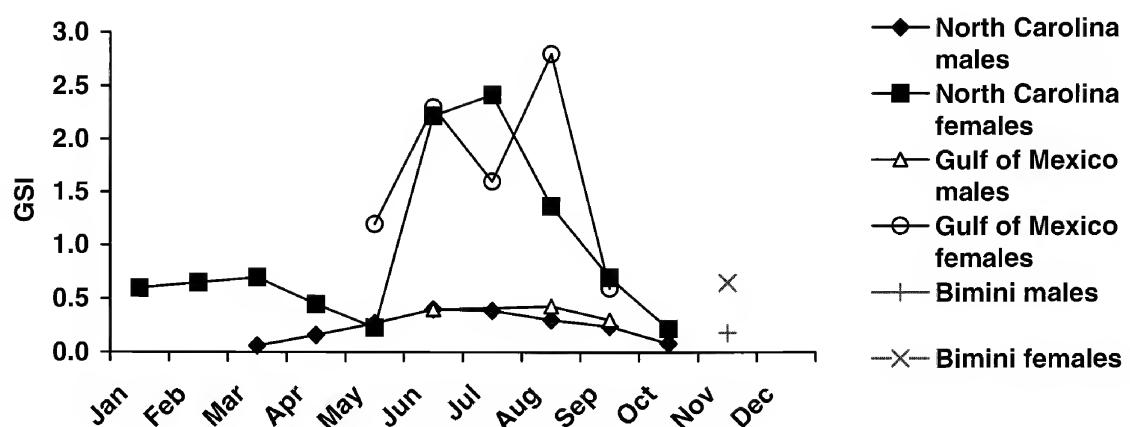


Figure 1. Monthly mean gonadosomatic indices (GSI) for male and female wahoo from the northern Gulf of Mexico (*n* = 52 females, 19 males, collected from May-September) and Bimini in the Bahamas (*n* = 13 females, 19 males, collected in November) (from Brown-Peterson et al. 2000), and North Carolina (*n* = 617 females, 178 males) (from Hogarth1976).

In Bermuda, based on macroscopic evaluation of gonadal condition, females appear to spawn from May through August, while males apparently have an extended period of sperm production, since a running ripe male was sampled in September, beyond the period when females are reproductively active (Luckhurst unpubl. data).

## MORPHOMETRICS, AGE, AND GROWTH

### Length and weight

Numerous length and weight measures have been recorded for wahoo across the WCA, and the various relationships between length, weight, girth, caudal fin span, otolith size, dorsal fin spine size and growth checks (Table 6) show little variation in equivalent relationships among localities. For the length-weight relationships, this is evidenced by the similar estimated weights for an 1100 mm fish (Table 6).

### Length-frequencies

Length-frequency data are available from landings of hook and line troll fisheries in a number of locations across the WCA. Most data sets show a similar wide size-range of wahoo, a unimodal size structure, and little indication of a modal progression in the size frequency over time. This latter observation has constrained attempts to use length-based methods to determine growth and mortality rates in particular for this species.

In St. Lucia, 11 years of wahoo size-frequency data from the artisanal fishery landings indicate an essentially unimodal size structure with a size range of 325–2125 mm FL and modal size classes in the range 775–975 mm FL (Neilson et al. 1999). The authors reported two closely spaced modes in the annual length-frequency distributions and suggested that they could represent either year classes or sexes if growth rate is sexually dimorphic, as is the case with some other scombrids. Neilson et al. (1999) also noted differences in the monthly mean size of wahoo landed but no clear modal progression. Note that parts of this same data set are also given in Murray and Sarvay (1987), Murray (1989), Murray and Nichols (1990) and Murray and Joseph (1996).

Beardsley and Richards (1970) provided size-frequencies from the recreational fishery in Florida sampled at a taxidermist. Although they acknowledged that the sample was likely biased towards larger specimens, they felt that it was reasonably representative of the wahoo caught, since a high proportion of the catch was retained for mounting by the recreational fishers. The size range for these Florida samples was 510–1750 mm FL, and there was no clear quarterly progression of the size frequency over a year.

In North Carolina, Hogarth (1976) reported that wahoo landed by the recreational fishery ranged in size from 760–2050 mm TL with the majority occurring in the 1110–1600 mm TL range. He reported some seasonal variation in size: first quarter (winter) fish ranged from 760–1650 mm TL (modal range: 1310–1500 mm TL), second quarter (spring) fish ranged from 860–1700 mm TL (modal range: 1010–1300 mm TL), and fall quarter fish modal range from 1210–1300 mm TL. There was no clear modal progression of size-frequency over the year. Wahoo landed in Bermuda had a unimodal size structure with a size range of 720–1800 mm FL and a modal size for both sexes combined of 1180 mm FL (Luckhurst and Trott 2000).

### Age, growth, and longevity

There is uncertainty involved in aging wahoo, as scales are unreadable and vertebrae annuli are inconsistent (see Hogarth 1976). Furthermore, otolith microstructure is complex, and there has been no successful validation of presumed annuli or daily growth checks in otoliths to date, although oxytetracycline (OTC) injections are part of a tagging program in Bermuda (see Nash et al. 2002). The few studies that have been conducted concur that wahoo is a relatively fast-growing species, particularly in the first year, and estimated size-at-age for wahoo from several locations and/or using different aging techniques are similar (Table 7). Most studies agree that wahoo probably has a life-span up to or in excess of 5–6 years.

In the southeastern Caribbean, Murray (1989) reported putative daily growth checks visible in a small number of whole sagittal otoliths ($n = 9$) from St. Lucia. Murray and Nichols (1990) noted that the otolith-based age estimates in the St. Lucia wahoo are probably erroneous. Sagittal otoliths ($n = 450$) from Barbados, St. Lucia, St. Vincent and Trinidad, and Tobago were examined for annual growth checks by Kishore and Chin (2001). Although sectioned otoliths have inconsistent growth checks, whole otoliths reveal relatively clear and consistent checks (presumed to be annuli) in most specimens from which size at age one year is estimated (Kishore and Chin 2001) (Table 7). These same authors reported 10 presumed annuli in the sagittae of the largest specimens, suggesting a longevity of up to 10 years.

**TABLE 6**

Morphometric relationships for wahoo from the western central Atlantic region. $S_R$ = sagittal radius, $SP_A$ = dorsal spine annuli, $SP_L$ = dorsal spine length, $SP_W$ = dorsal spine weight, $SP_D$ = dorsal spine diameter.

| Area | Location | Relationship (units) | Sex | Sample size (n) | Equation | Est. kg at 1100 mm | Reference |
|---|---|---|---|---|---|---|---|
| Southeastern Caribbean | Trinidad & Tobago | Length-whole weight (Wt in kg, L in cm) | All | 391 | $Wt = 8.9 \times 10^{-8} \times FL^{3.862}$ | 6.8 | Kishore and Chin 2001 |
| | St. Lucia | Length-gutted weight (Wt in g, L in mm) | All | 195 | $Wt = 1.039 \times 10^{-6}\, TL^{3.206}$ | 5.9 | Murray 1989, Murray 1999 |
| | | | | 36 | $Wt = 2.991 \times 10^{-6}\, FL^{3.072}$ | 6.6 | |
| | | | | ? | $Wt = 4.06 \times 10^{-6}\, FL^{3.028}$ | 6.2 | George et al. 2001 |
| | | Length-length (mm) | All | 75 | $FL = 1.086 + 0.950\, TL$ | - | Murray 1989, Murray 1999 |
| | | Length-sagittal radius (mm) | All | 9 | $TL = 16.56\, S_R^{1.929}$ | - | Murray 1989 |
| Northern Caribbean | Bahamas | Length-whole weight (Wt in kg, L in cm) | All | 25 | $Wt = 1.741 \times 10^{-6} \times TL^{3.221}$ | 6.5 | Hogarth 1976 |
| | ? | | | 57 | $Wt = 4.691 \times 10^{-5} \times TL^{2.567}$ | 8.2 | |
| | | | | 91 | $Wt = 2.037 \times 10^{-6} \times TL^{3.201}$ | 7.0 | |
| | | Length-dorsal spine annuli (mm) | All | 22 | $FL = 748.406 + 214.69\, SP_A$ | - | Franks et al. 2000 |
| Gulf of Mexico | Northern | Length-dorsal spine length (mm) | All | 59 | $FL = 452.736 + 12.852\, SP_L$ | - | Franks et al. 2000 |
| | | Length-dorsal spine wt (L in mm, Wt in g) | All | 63 | $FL = 862.358 + 704.691\, SP_W$ | - | |
| | | Length-dorsal spine diameter (mm) | All | 63 | $FL = 365.683 + 277.002\, SP_D$ | - | |
| | | Length-dorsal spine annuli (mm) | All | 63 | $FL = 735.151 + 186.01\, SP_A$ | - | |
| | | Dorsal spine diameter-dorsal spine annuli (mm) | All | 55 | $SP_D = 1.610 + 0.561\, SP_A$ | - | |
| Eastern USA 1970 | Florida | Length-whole weight (Wt in kg, L in cm) | ? | ? | $Wt = 3.647 \times 10^{-6} \times TL^{3.082}$ | 8.2 | Beardsley and Richards |
| | | | All | 746 | $Wt = 1.544 \times 10^{-6} \times FL^{3.294}$ | 7.1 | Hogarth 1976 |
| | North Carolina | Length-whole weight (Wt in kg, L in cm) | All | 795 | $Wt = 1.845 \times 10^{-6} \times TL^{3.218}$ | 6.87 | |
| | | | Female | 617 | $Wt = 2.113 \times 10^{-6} \times TL^{3.192}$ | 7.0 | |
| | | | Male | 178 | $Wt = 2.157 \times 10^{-6} \times TL^{3.181}$ | 6.7 | |
| | | Length-length (cm) | All | 795 | $TL = 2.452 + 1.016\, FL$ | - | |
| | | Length-caudal fin span (cm) | All | 795 | $TL = 2.832 + 1.016\, CF$ | - | |
| | | Length-girth (cm) | All | 795 | $TL = 0.656 + 1.020\, G$ | - | |
| | | Weight-girth (Wt in kg, L in cm) | All | 795 | $Wt = 16.765 + 0.644\, G$ | - | |
| | | Length-sagittal radius(mm) | ? | ? | $TL = 34.14 + 0.599\, S_R$ | - | |
| Atlantic | Maryland | Length-whole weight (Wt in kg, L in cm) | All | 32 | $Wt = 1.517 \times 10^{-6} \times TL^{3.247}$ | 6.4 | |
| | Bermuda | Length-whole weight (Wt in kg, L in cm) | All | 72 | $Wt = 0.446 \times 10^{-6} \times TL^{3.502}$ | 6.3 | Hogarth 1976 |

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## TABLE 7

Estimated mean lengths at age for wahoo from the western central Atlantic obtained using unvalidated growth checks in hard parts. For ease of comparison total lengths for wahoo from Trinidad and Tobago and North Carolina have been converted to fork lengths (using the length-length conversion equations given for wahoo in the same geographical area).

| Location | Length (mm FL) | | | | | | Reference |
|----------|-------|-------|-------|-------|-------|-------|-----------|
| | Age 1 | Age 2 | Age 3 | Age 4 | Age 5 | Age 6 | |
| Trinidad & Tobago | 847 | - | - | - | - | - | Kishore and Chin 2001 |
| Bahamas | 961 | 1179 | 1391 | - | - | - | Franks et al. 2000 |
| Gulf of Mexico | 937 | 1081 | 1325 | 1536 | 1690 | 1749 | Franks et al. 2000 |
| North Carolina | 1105 | 1216 | 1368 | 1569 | - | - | Hogarth 1976 |

Wahoo from the northern Gulf of Mexico ($n = 63$) and from Bimini in the Bahamas ($n = 22$) have been tentatively aged using unvalidated annuli in thin-sectioned dorsal fin spines (Franks et al. 2000) (Table 7). Although the first five dorsal fin spines were examined, only the first (largest) spine appeared to have unambiguous translucent bands (presumed annuli). From Bimini, there was no difference between the sexes in size-at-age estimates. From the northern Gulf, up to six annuli were detected in the largest specimens, and again there was no difference in size-at-age estimates between males and females. Sagittal otoliths were also examined from the same fish specimens by Franks et al. (2001) who attempted to enhance the contrast and visibility of vague presumed annual growth checks using a variety of stains and etching techniques. However, since bands were not reliably enhanced in the majority of specimens, they concluded that this was not a useful technique for this species.

For wahoo off the lower Florida coast, Beardsley and Richards (1970) suggested a summer growth rate of 30–40 mm FL per month, based on modal progression of wahoo size-frequency data from a taxidermist. Hogarth (1976) aged wahoo from North Carolina using presumed annuli in whole sagittal otoliths. He used back calculation of lengths at annulus formation (using the otolith radius to body length relationship) to estimate length-at-age and suggested a five year life-span, but noted that the majority (78%) of individuals sampled were less than three years old.

Presumed annuli as well as apparent daily growth checks are clearly visible on the sagittal otoliths from Bermuda, under a scanning electron microscope (Luckhurst et al. 1997). However, they do not provide any size-at-age data in this preliminary study and indicate that validation of the periodicity of the growth checks will be attempted with an otolith marking (OTC) tag-recapture program in Bermuda. This has not yet yielded any validation results, but a single recapture indicated rapid growth from 5 to 15 kg in an individual at liberty for 10 months (Nash et al. 2002).

### Growth parameters

Von Bertalanffy growth parameters have been estimated for wahoo from several locations across the WCA using unvalidated growth marks in hard parts and/or length-frequency data to estimate size-at-age over a range of size classes (see Murray 1989, Murray and Sarvay 1987, Murray and Joseph 1996, Kishore and Chin 2001, George et al. 2001, SAFMC 2000). Asymptotic length ($L_\infty$) estimates range from 1410 mm TL to 2210 mm FL, and instantaneous growth (k) estimates vary widely from 0.152–3.93 (on an annual basis). Given the stated uncertainties in all of the estimates and the fact that there is a wide range in estimates, even for wahoo from the same location (e.g., Murray 1989), they should be considered as highly preliminary.

### MORTALITY

There have been a few estimates of mortality rates for wahoo from the WCA. Off St. Lucia in the southeastern Caribbean, preliminary estimates place total mortality between 69 and 90% annually, natural mortality between 38 and 44% annually, and fishing mortality between 46 and 83% annually (Murray and Sarvay 1987, Murray 1989 and Murray and Joseph 1996). However, these mortality estimates are likely to be biased due to the lack of modal progression in the length-frequency distributions (Neilson et al. 1999). George et al.'s (2001) estimates of annual total mortality (99%), natural mortality (47%) and fishing mortality

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(98%) are likely to be unrealistically high, given the possibility that the larger fish may be migrating out of the sampling area. Hogarth (1976) estimated total mortality for wahoo collected off North Carolina at between 35 and 38% annually. Like the growth rate parameters, these mortality estimates from the WCA should be considered as highly preliminary, given the high variation in estimates even for fish from the same location and the general lack of modal progression in the length-frequency data on which they are based.

## FOOD AND FEEDING HABITS

There have been a few studies of wahoo diet and feeding habits in the WCA which indicate that it is primarily piscivorous, with fishes accounting for more than 70% of the total number of food items (Figure 2) and more than 90% of the total volume and occurrence of prey items in the northern Gulf of Mexico and the US south Atlantic states (Table 8) (see Hogarth 1976, Manooch and Hogarth 1983). Collette and Nauen (1983) and Collette (in press) list tunas (Scombridae), flyingfishes (Exocoetidae), herrings and pilchards (Clupeidae), scads (*Decapterus* spp.), and lanternfishes (Myctophidae) as common prey of wahoo in the WCA. In Bermuda, little tunny (*Euthynnus alletteratus*) and flyingfishes are common vertebrate prey (Luckhurst unpubl. data from 150 wahoo caught Sep–Oct). Invertebrate prey, comprising mostly squids, varies in importance with location and accounts for between 2.6 and 26.3% of all food items consumed by wahoo from the northern Gulf of Mexico (Manooch and Hogarth 1983) and the US south Atlantic states (Hogarth 1976, Manooch and Hogarth 1983) (Figure 2). Squids are also listed as important prey items for wahoo from the WCA (Collette and Nauen 1983, Collette in press) and Bermuda (Luckhurst unpubl. data). The groups of key importance to the diet are similar among locations and comprise fast swimming pelagic families (scombrids, exocoetids, clupeids, and cephalopods) as well as those which are generally associated with floating material (stromateids, juvenile carangids, diodontids, and balistids) (Figure 2). This indicates that wahoo forages in open water as well as below floating material. Manooch and Hogarth (1983) note that small items do not feature in the diet, probably because wahoo lack gill rakers, and there is no apparent relationship between predator and prey size since wahoo can bite large prey into pieces. Wahoo is one of the fastest pelagic species, attaining bursts of speed exceeding 75 km per hour (Joseph et al. 1988). Consequently it is able to capture a wide range of
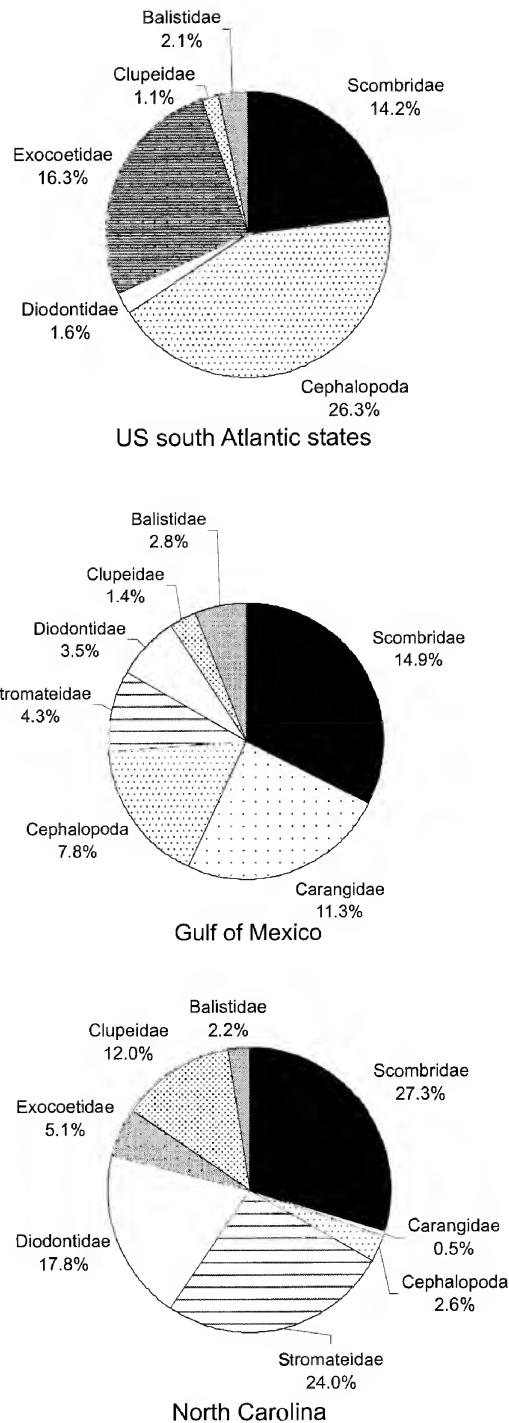


Figure 2. Comparison of the diet of wahoo from the western central Atlantic based on numerical abundance of major prey items in stomachs. Data from the Gulf of Mexico (*n* = 95 fish from northwest Florida, Louisiana and Texas) and the US south Atlantic states (*n* = 172 fish from North Carolina, South Carolina, Georgia, east coast of Florida and Florida Keys) were collected in 1980–1981 and are from Manooch and Hogarth (1983). Data from North Carolina (*n* = 645 fish) were collected in 1964–1971 and are from Hogarth (1976).

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## TABLE 8

Diet of wahoo from the northern Gulf of Mexico and the US south Atlantic states (1980–1981) showing the relative importance of prey families or higher taxa assessed by percent frequency of occurrence in stomachs containing food and by percent of total volume of prey items. Data are extracted from Manooch and Hogarth (1983).

| Location | US Gulf of Mexico | | US south Atlantic states | |
|---|---|---|---|---|
| Total no. fish examined | 95 | | 172 | |
| Total no. fish prey species | 13 | | 11 | |
| Total stomachs w. food | 71 | | 123 | |
| Total prey volume (ml) | 3717 | | 7543 | |
| **Freq. of occurrence** | **% occurrence** | **Rank** | **% occurrence** | **Rank** |
| **Fish** | **91.5** | . | **90.2** | . |
| Unid. fish | 59.2 | . | 47.2 | . |
| Clupeidae | 2.8 | . | 1.6 | 5 |
| Exocoetidae | 0.0 | . | 21.1 | 2 |
| Echeneidae | 1.4 | . | 0.0 | . |
| Carangidae | 15.5 | 2 | 0.0 | . |
| Coryphaenidae | 1.4 | . | 0.0 | . |
| Scombridae | 22.5 | 1 | 19.5 | 3 |
| Stromateidae | 1.4 | . | 0.0 | . |
| Bothidae | 0.0 | . | 0.8 | . |
| Balistidae | 4.2 | 5 | 1.6 | 5 |
| Diodontidae | 5.6 | 4 | 2.4 | 4 |
| **Invertebrates** | **14.1** | . | **?** | . |
| Cephalopoda | 14.1 | 3 | 25.2 | 1 |
| Crustacea | 0.0 | . | 0.8 | . |
| **Volume** | **% volume** | **Rank** | **% volume** | **Rank** |
| **Fish** | **99.2** | . | **91.9** | . |
| Unid. fish | 19.7 | . | 19.9 | . |
| Clupeidae | 2.3 | . | 0.5 | . |
| Exocoetidae | 0.0 | . | 22.4 | 2 |
| Echeneidae | 0.4 | . | 0.0 | . |
| Carangidae | 15.4 | 2 | 0.0 | . |
| Coryphaenidae | 5.0 | . | 0.0 | . |
| Scombridae | 51.7 | 1 | 44.6 | 1 |
| Stromateidae | 3.5 | 3 | 0.0 | . |
| Bothidae | 0.0 | . | 0.1 | . |
| Balistidae | 0.2 | . | 1.9 | 5 |
| Diodontidae | 1.1 | 4 | 2.5 | 4 |
| **Invertebrates** | **0.5** | . | **8.0** | . |
| Cephalopoda | 0.5 | 5 | 8.0 | 3 |
| Crustacea | 0.0 | . | 0.0 | . |

prey species while foraging in the water column. Interestingly, although Scombridae is one of the most important prey families overall (Figure 2, Table 8), there have been no reported incidences of cannibalism.

## PARASITES

Although there have been relatively few studies of wahoo parasites from the WCA, Hogarth (1976) and Manooch and Hogarth (1983) found that 80.5% of stomachs from North Carolina, the US south Atlantic states, and the Gulf of Mexico contain 1–13 (average 2) large digenetic trematodes (tentatively identified as *Hirudinella ventricosa*). Levels of infection are the same for males and females, independent of host size, and there is no discernible effect of the parasites on the condition of individuals (Manooch and Hogarth 1983). However, geographical differences in the level of infestation are evident, with wahoo from the east and south coasts of Florida having the lowest levels. Wahoo from the Bahamas and North Carolina are also occasionally infested with a monostome (tentatively identified as *Didymocystis coastesi*) in the eye muscle (Manooch and Hogarth 1983). In Bermuda, Luckhurst (unpubl.) examined wahoo stomachs ($n = 150$) and found that 94% contained between 1–12 (average 2) large digenetic trematodes. He also reported parasitic copepods attached close to the caudal fin of some Bermuda wahoo. The total parasite fauna of wahoo is low, with only 11 different parasites (including a copepod worm, a fluke, a tissue fluke, 2 gill worms, 3 tapeworms, and 3 copepods) from western Atlantic specimens. Cressey and Cressey (1980) and Cressey et al. (1983) list seven species (6 genera) of parasitic copepods from wahoo (locations of samples not specified), with infestation rates being highest for *Brachiella thynni* (61%), *Gloiopotes hygomianus* (42%), and *Caligus productus* (17%).

## STOCK STRUCTURE

Several authors have commented generally on the possible nature of the stock structure of wahoo in the WCA (e.g., Hunte 1987, Mahon 1990, 1996, Neilson et al. 1999), based on sparse length-frequency and seasonality data. All agree that the data are insufficient to draw any firm conclusions but consider it reasonable to assume that wahoo is likely to have a shared-stock status within the WCA, either straddling or migrating between the EEZs of two or more countries. Manooch and Hogarth (1983) speculate that differences in levels of

infestation of wahoo by the giant trematode, observed between the east and south coasts of Florida and the rest of the US south Atlantic states and the northern Gulf of Mexico, may indicate separate stocks. However, they conclude that it is more likely caused by slight geographical differences in diet. Lacking any substantive data suggesting otherwise, the SAFMC (1998, 2000) is using a working hypothesis of a single-stock model for preparation of a management plan for wahoo.

More recent genetic data concur with earlier suggestions that wahoo in the WCA probably comprise a single unit stock. A preliminary study of genetic variation, using genomic DNA of 78 wahoo from across the WCA (Bermuda, Gulf Coast of the USA, Dominica, and Tobago) and just two RAPD (Random Amplified Polymorphic DNA) primers, indicates genetic homogeneity consistent with a single stock (Collymore 2000). A follow-up study by Constantine (2002) tested the single-stock hypothesis, using RAPD markers obtained from five primers to examine 114 wahoo from six locations in the WCA (Bermuda, Gulf Coast of the USA, Dominica, St. Lucia, Barbados, and Tobago) and an outgroup sample ($n = 33$) from the mid-Atlantic (Rocedos São Pedro e São Paulo, off Brazil). A high level of genetic variation within and among samples from different locations in the WCA, but with no clear separation, supports the single-stock hypothesis. Furthermore, a lack of genetic separation between the WCA and the mid-Atlantic samples suggests that the stock boundary extends beyond the WCA (Constantine 2002).

Garber et al. (2001) provide a molecular characterisation of the mtDNA control region of the wahoo genome, including the structure and sequence of the flanking tRNA genes and identification of a hypervariable segment at the 5′ end of the control region. This will be useful in future studies for designing specific primers and selecting appropriate restriction enzymes for this portion of the genome, to further test the null hypothesis of a single stock.

## STATUS OF THE RESOURCE

Although ICCAT monitors landings of wahoo throughout the Atlantic, they have not yet attempted to conduct any assessments nor to manage this species. There has been no region-wide stock assessment in the WCA and, as such, the status of the resource remains uncertain. A sub-regional assessment of wahoo in the southeastern Caribbean, using a combination of length-based models (length-based catch curve and length-based virtual population analysis) suggests an annual

maximum sustainable yield (MSY) of 2,137 mt corresponding to a fishing mortality of 29% annually ($F_{msy}$ = 0.34 $y^{-1}$) (George et al. 2001). The stock was deemed severely overfished, given that their estimates of current annual fishing mortality greatly exceeded $F_{msy}$. They also estimated maximum yield per recruit (YPR) to occur at an annual fishing mortality of 66% ($F_{max}$ = 1.09) (for the present size-at-first capture of 900 mm FL) and annual fishing mortality rates of 49 and 37% ($F_{max}$ = 0.68 and 0.47) to maintain the stock at 30 and 40% of its initial biomass per recruit (BPR) respectively. Again, the indication is of severe overfishing currently taking place. However, the results of this assessment are highly uncertain and dependent on dubious growth parameters. They are also likely to be biased, because there is strong indication that the southeastern Caribbean population is not a separate stock from that present in the rest of the WCA; therefore, the catch data used only represent about 20% of the total catch from the WCA stock. Moreover, the classification of the stock as severely overfished is based on current mortality estimates that are highly uncertain (George et al. 2001).

The Gulf of Mexico Fishery Management Council uses estimates of mean annual landings as a proxy for MSY and current estimates oscillate between 650 and 750 mt (FAO 2002a). Again, this is unlikely to be a realistic MSY for the stock, given that the Gulf of Mexico population is probably not a separate stock. The US NMFS has not done any assessment or defined stocks of wahoo in US waters.

There have been a number of studies examining local or sub-regional time-series of wahoo catch and effort data as possible indicators of declines in stock abundance. None of these studies have found any evidence of decline, but there is some question as to whether the available catch per unit effort (CPUE) data sets are suitable as abundance indicators for wahoo, since increases in fishing power may not have been adequately accounted for in the unit of effort used (e.g., catch per trip). Furthermore, wahoo is often part of a multi-species catch per trip and not necessarily the primary target. For example, in the southeastern Caribbean island of Barbados, the average annual catch per trip for "kingfish" (primarily wahoo) shows an increase over the years 1960–1982 which is attributed to increased fishing power per trip, rather than an actual increase in the abundance of wahoo (Hunte 1987). Mahon et al. (1990) examined CPUE (catch per trip) data series from several islands in the southeastern Caribbean chain ranging from 32 years (1958–1989) in

Barbados, 11 years (1979–1989) in St. Vincent, 8 years (1982-1989) in Grenada, to 5 years (1985–1989) in St. Lucia. No declines were evident, but they reported significant inter-annual variability in the mean CPUE and a lack of synchrony in the annual abundance indices among islands. They concluded that wahoo have a patchy distribution in this sub-region which varies from year to year but has not declined overall, or that the CPUE indices used are not a good index of wahoo abundance. In the US Virgin Islands, CPUE data from the recreational fishery for the years 1967–1979 showed no net long-term change in catch per trip over this 12-year period (Hunte 1987). In North Carolina a CPUE time-series from the recreational fishery off Hatteras and Oregon Inlet, showed a steady increase from around 0.12 fish per trip in the mid 1960s to 0.35 fish per trip in the early 1970s and a slight concomitant increase in fishing effort (number of trips) (Hogarth 1976). This he attributed to improved fishing techniques, rather than a real increase in the abundance of wahoo in the Gulf Stream over the 9-year (1964–1972) period. In Bermuda, where wahoo is the primary target, mean annual CPUE data show no trends over the period 1987 to 1996, suggesting no marked changes in the abundance of wahoo in Bermuda's waters over 11 years (Luckhurst and Trott 2000).

## DATA NEEDS

Based on the one-stock hypothesis for wahoo in the WCA, a regional approach to stock assessment and management will be required. Recreational and commercial fishing pressure on wahoo is continuing to rise throughout much of the region and there is concern that the stock is, or soon will be, negatively impacted and should be managed. However, assessment and management attempts will be constrained by the current lack of knowledge in several key areas. Significant improvements in wahoo catch and effort data collection and reporting are needed to include all countries participating in the fishery and to obtain reliable abundance estimates and exploitation trends for this stock. Wahoo migration and movement patterns are inadequately known. These data are necessary for determining critical habitats (e.g., important spawning areas), determining relative spatial and temporal distribution of the resource among the EEZs of the countries in the WCA, and improving the interpretation of genetic stock structure data. Uncertain age and growth estimates and a general lack of modal progression of fishery-dependent length-frequency data over time are a significant con-

straint to using age and length-based approaches to stock assessment and to determining current mortality and exploitation rates. Data on reproductive characteristics (e.g., fecundity-length relationships, age and size at maturity, spawning season) are required from a larger sample size and for a greater geographical area to improve confidence in attempts to assess the impacts of management actions on spawning stock biomass and for assisting in the appropriate choice of minimum harvest sizes and closed seasons. A more comprehensive analysis of genetic stock structure is required to determine the relationship between wahoo from the WCA and the entire Atlantic Ocean and thus whether assessment and management of this species will need to be expanded to a broader geographical area.

## ACKNOWLEDGMENTS

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# Status and Habitat Characteristics of the Saltmarsh Topminnow, *Fundulus jenkinsi* (Evermann) in Eastern Mississippi and Western Alabama Coastal Bayous

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# STATUS AND HABITAT CHARACTERISTICS OF THE SALTMARSH TOPMINNOW, *FUNDULUS JENKINSI* (EVERMANN) IN EASTERN MISSISSIPPI AND WESTERN ALABAMA COASTAL BAYOUS

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*ABSTRACT* The saltmarsh topminnow, *Fundulus jenkinsi* (Evermann, 1892), occurs sporadically along the northern Gulf of Mexico and appears to prefer *Spartina* habitat. Throughout its range, it is considered rare or threatened and has been placed on the US Federal Register's List of Candidate Species. In order to determine the status and habitat characteristics of this species, we examined collections from 1985–1986, 1996, 1999, and 2001 from eastern Mississippi and western Alabama. We report on 868 *F. jenkinsi* collected in 82 locations using 414 seine hauls and 420 Breder traps over 40 dates. Results using all collections indicated *F. jenkinsi* is not as abundant as other fundulids in this area but is more abundant than previously thought. We also documented the first records for this species from the Pascagoula River drainage. For the Breder trap collections only, a stepwise linear regression indicated that water temperature and salinity explained 39.7% of the variance in $\log_{10}$(mean CPUE + 0.5) over the time of this study and this relationship was significant (ANOVA, $F_{3,59} = 13.95, P < 0.001$). The equation $\log_{10}$(mean CPUE + 0.5) = 1.623 − 0.0150 (salinity) + 0.77 (depth) − 0.0584 (water temperature) indicated that mean CPUE of *F. jenkinsi* was higher when salinity and water temperature were lower. Using bag seine and Breder trap data, this species was most abundant (90.7% of total) in salinities ≤12‰ while being mainly collected in water depths near 0.5 m and water temperatures ≥ 20.0°C. We feel the use of sampling gear designed to collect resident marsh fishes is imperative and use of other gear types and/or variation in annual rainfall and the subsequent extent and patchiness of low salinity salt marsh area from year to year may explain why this species appears rare or absent in most fish studies of the northern Gulf of Mexico. Because of its distribution in low-salinity bayou habitats, this small fundulid will probably be continually placed in situations where the habitat will be impacted due to development.

## INTRODUCTION

The saltmarsh topminnow, *Fundulus jenkinsi* (Evermann), occurs sporadically in *Spartina* marsh along the Gulf Coast from Galveston, Texas to Escambia Bay, Florida (Bailey et al. 1954, Thompson 1980, Boschung 1992). Thompson (1980) suggested that *F. jenkinsi* is mainly found where salinities range between 1 and 4‰. However, Griffith (1974) reviewed existing salinity tolerance data throughout its range and noted it has been found in salinities up to 15–20‰. Little is known, however, about the distribution and habitat characteristics of the saltmarsh topminnow in coastal marshes of the northern Gulf of Mexico. Simpson and Gunter (1956) collected 24 individuals from Texas *Spartina* marshes and discussed some aspects of their ecology. In west-central Louisiana *Spartina* marshes, Neill and Turner (1987), Rozas (1992a, 1992b) and Rozas and Reed (1993) documented this species in oligo- to mesohaline sites in low numbers using various collecting techniques. However, Peterson and Turner (1994) found that *F. jenkinsi* was the ninth most abundant species in a Louisiana *Spartina* marsh when collected

with flume nets. Peterson and Ross (1991) collected 240 *F. jenkinsi* in Old Ft. Bayou, a coastal river in Mississippi. Ross and Brenneman (1991) also mention records of this species from coastal rivers and the Pearl River drainage and indicate that it has not been collected in the Pascagoula River drainage. In coastal Alabama, Swingle and Bland (1974) recorded 177 individuals from marshes of the Mobile Bay area between 2–25‰. In Florida, Bailey et al. (1954) collected 80 individuals from near the confluence of the Escambia River and Escambia Bay where surface salinity was 4.5‰. Gilbert and Relyea (1992) noted this species is considered "threatened" in Florida in part due to its restricted panhandle distribution, strong anecdotal evidence of its use of *Spartina* marsh habitat, and the fact that coastal marsh habitat world-wide is being altered. Gilbert and Relyea (1992) suggest that *Spartina* marsh should be conserved to protect this rare species.

Although it has been suggested that the distribution of *F. jenkinsi* is coupled with that of *Spartina* marsh, few quantitative data exist. Published data indicates that few or no *F. jenkinsi* are collected outside *Spartina* marsh habitats. It is clear, however, that this species
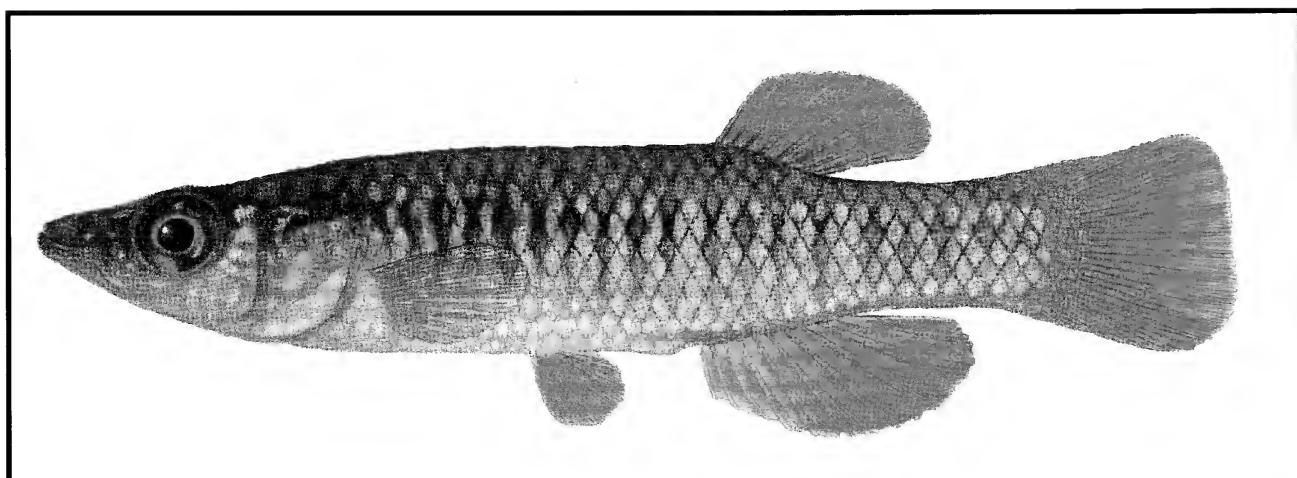
**Figure 1. Saltmarsh topminnow,** *Fundulus jenkinsi* **(Evermann). Male, 43 mm SL (UAIC 10853.04), Dauphin Island, Mobile County, July 14, 1993. Illustration by Joseph R. Tomelleri is copyrighted.**

appears to be a coastal fundulid which is most abundant within intermediate to low salinity habitats. The majority of these habitats in the northern Gulf of Mexico are either *Spartina alterniflora* or *Juncus roemerianus* (Tiner 1993). Coupling the low relative abundance and patchy distribution of *F. jenkinsi* along the northern Gulf of Mexico with increased development pressure suggests the need for the quantification of the habitat characteristics. The objective of this study was to document the distribution, catch-per-unit-effort (CPUE) and habitat characteristics of the saltmarsh topminnow, *F. jenkinsi* (Figure 1), in coastal bayous within eastern Mississippi and western Alabama and to review what is known about its habitat throughout its range.

## STUDY LOCATIONS

The quantitative data for this study were collected in summers 1996 and 1999 but we also include data from Peterson (1987) and Peterson and Ross (1991) and recent unpublished data. All of these collections were made in small bayous ranging from Biloxi, Mississippi to Mobile, Alabama (Figure 2, Table 1). In Mississippi, *F. jenkinsi* were collected from a total of 57 locations in 1996 and 1999. We collected in 21 locations on 7 dates in 1996 (between 10 July and 23 September) from Halstead, Stark, Simmons, Heron, Graveline, and Mary Walker Bayous, and Grand Bayou on Deer Island. In 1999, we collected in 36 locations on 12 dates (between 26 May and 8 September) from Sioux Bayou, Snake Bayou, Coleson Bayou, Lowry Bayou, Krebs Lake, Lake Catch-em-all, McInnis Bayou, and around Rabbitt Island, Middle Bayou, Clay Bayou, Southwest Bayou, Mattie Clark Bayou, Bayou Cumbest, Bayou Heron, a

bayou off of Bangs Lake, Crooked Bayou, and North Bayou. In Alabama, we collected in 20 locations on 7 dates (between 6 and 25 August) in 1999 from Bayou La Fouche, a tidal creek of Bayou La Fouche, Little River, Portersville Bay, Bayou Sullivan, Negro Bayou, Fowl River West, Fowl River East, Bayou Caddy, Grand Bayou, and Bulls Bay Bayou. These represent 420 Breder trap collection sites plus 36 seine haul sites in addition to the 258 seine collections in Peterson (1987) and Peterson and Ross (1991) and unpublished collections (*n* = 17 seine hauls) taken in 2001 from Simmons Bayou (on 25 January; Peterson and Slack, unpublished). The dominant emergent aquatic vegetation associated with all sites was *J. roemerianus* or *S. alterniflora*.

## MATERIALS AND METHODS

We surveyed bayous of eastern Mississippi from Old Fort Bayou to bayous of western Mobile Bay with seine nets or Breder traps (Breder 1960) depending on date and system. Specific information of collection techniques for the 1985–1986 and 1996 data sets can be found in Peterson and Ross (1991) and Fulling et al. (1999), respectively. Four Breder traps per collection site were used in 1996 whereas six traps were used per site in 1999. These traps were constructed of 1/4 inch clear Plexiglas which was fused with methyl chloride. The traps had a 12 mm opening at the base of the "V" (the dimensions of the two wings of the V were 15 x 15 cm) and the box on the trap was 30 x 15 cm. These traps were set at high tide about 1.5 m apart and fished until the water passed the two wings, approaching low tide. Fishing from high to low tide was considered a CPUE.
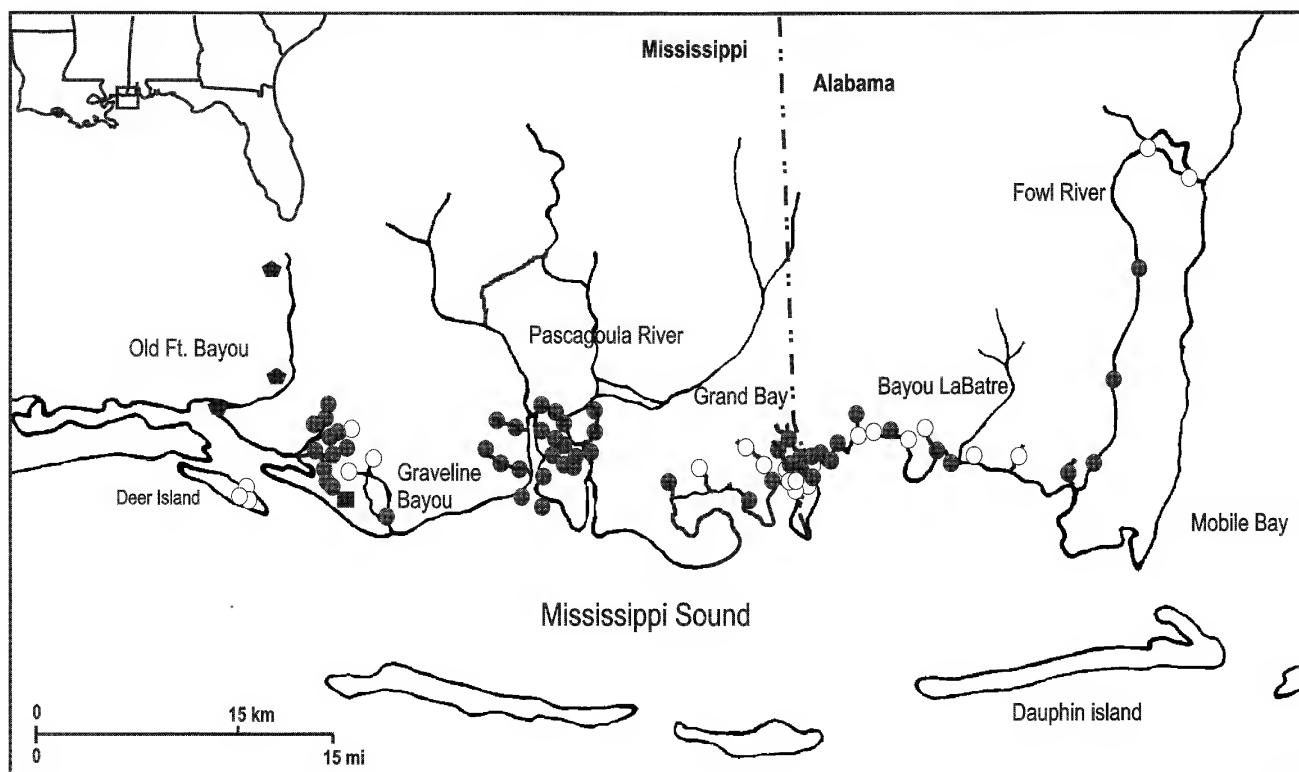
Figure 2. Map of the sampling sites in eastern Mississippi and western Alabama. Closed circle are 1996 and 1999 sites where *F. jenkinsi* was collected; open circles are 1996 and 1999 sites where *F. jenkinsi* were not collected; closed boxes are 2001 Simmons Bayou sites; and pentagons are Peterson and Ross 1991 sites.

Physical-chemical data were taken in surface waters near one trap when the traps were set and these data were used in analysis and presentation. All fish were euthanized in MS-222, fixed in 10% formalin for one week and then transferred to 70% ethanol for preservation. At each site we measured water temperature (°C), dissolved oxygen (DO; mg/l), turbidity (NTU) and salinity (‰). Salinity and water temperature were monitored with a YSI S-C-T meter (model 33), DO with a YSI oxygen meter (model 58), and turbidity with a LaMotte Digital turbidity meter. We geo-referenced each sample site with a Garmin 45 GPS system. Fish were catalogued into the Gulf Coast Research Laboratory (GCRL) Ichthyological Museum or the Mississippi Museum of Natural Science (MMNS).

Because the physical-chemical factors were measured at a set of four or six traps, we used mean CPUE in subsequent data analyses. A stepwise linear regression of mean CPUE ($x$ + 0.5) as the dependent variable and all physical-chemical factors as the independent variables was calculated. All data were analyzed on SPSSW (version 10.0, SPSS Inc., Chicago, Ill.) and considered significant if $P < 0.05$.

## Results

In four surveys (1985–1986, 1996, 1999, and 2001), we collected 868 *F. jenkinsi* in 311 seine hauls and 420 Breder trap collections over 40 dates in 82 locations (Figure 2). *Fundulus jenkinsi* was collected in 28 of 36 bayou systems examined in 1996 and 1999. Sites where we collected *F. jenkinsi* in our 1996 and 1999 surveys (Table 2) were similar in terms of dominant vegetation and range of environmental characteristics to those noted in 1985–1986 from Old Ft. Bayou during the appropriate season, and in 2001 collections in Simmons Bayou. Breder trap collections produced 393 *F. jenkinsi* (45.3% of total) whereas 475 (54.7% of total) were collected with bag seines (3 or 6 m in length). For the Breder trap collections only, a stepwise linear regression of $\log_{10}$ (mean CPUE + 0.5) as the dependent variable and all physical-chemical factors as the independent variables indicated that salinity, depth, and water temperature explained 39.7% (adjusted $r^2$) of the variance over the time of this study and this relationship was significant (ANOVA, $F_{3,59} = 13.95, P < 0.001$). The equation $\log_{10}$(mean CPUE + 0.5) = 1.623 − 0.0150 (salinity) + 0.77 (depth) − 0.0584 (water temperature) indicates that mean CPUE of *F. jenkinsi* was higher when

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## TABLE 1

**Sampling localities and collection data. All 1996 collections used four Breder traps; all 1999 collections used six Breder traps. 2001 collections were made with a 3 m haul seine.**

| Date | Bayou | Latitude/Longitude | Museum # | # Specimens |
|---|---|---|---|---|
| 7/10/96 | Halstead Bayou | 30E 23.75' N 88E 47.99' W | GCRL26975 | 9 |
| 7/10/96 | Halstead Bayou | 30E 23.75' N 88E 47.85' W | GCRL26982 | 3 |
| 7/10/96 | Halstead Bayou | 30E 23.70' N 88E 47.68' W | GCRL26988 | 4 |
| 7/11/96 | Stark Bayou | 30E 23.91' N 88E 47.51' W | | 0 |
| 7/11/96 | Stark Bayou | 30E 23.83' N 88E 47.48' W | GCRL26998 | 6 |
| 7/11/96 | Stark Bayou | 30E 23.70' N 88E 47.54' W | GCRL27001 | 5 |
| 7/29/96 | Grand Bayou (Deer Island) | 30E 22.28' N 88E 50.28' W | | 0 |
| 7/29/96 | Grand Bayou (Deer Island) | 30E 22.29' N 88E 50.14' W | | 0 |
| 7/29/96 | Grand Bayou (Deer Island) | 30E 22.39' N 88E 50.13' W | | 0 |
| 8/09/96 | Heron Bayou | 30E 24.16' N 88E 46.33' W | GCRL27017 | 1 |
| 8/09/96 | Heron Bayou | 30E 24.04' N 88E 46.38' W | GCRL27024 | 2 |
| 8/09/96 | Heron Bayou | 30E 23.80' N 88E 46.31' W | GCRL27028 | 13 |
| 8/26/96 | Simmons Bayou | 30E 23.50' N 88E 45.20' W | GCRL27035 | 10 |
| 8/26/96 | Simmons Bayou | 30E 23.50' N 88E 45.40' W | GCRL27043 | 5 |
| 8/26/96 | Simmons Bayou | 30E 22.78' N 88E 46.05' W | GCRL27048 | 2 |
| 8/28/96 | Graveline Bayou | 30E 22.43' N 88E 42.64' W | | 0 |
| 8/28/96 | Graveline Bayou | 30E 22.69' N 88E 41.99' W | | 0 |
| 8/28/96 | Graveline Bayou | 30E 22.29' N 88E 40.35' W | GCRL27049 | 4 |
| 9/23/96 | Mary Walker Bayou | 30E 22.78' N 88E 46.05' W | GCRL27050 | 5 |
| 9/23/96 | Mary Walker Bayou | 30E 22.78' N 88E 46.05' W | GCRL27051 | 22 |
| 9/23/96 | Mary Walker Bayou | 30E 22.78' N 88E 46.05' W | GCRL27052 | 23 |
| 5/26/99 | Sioux Bayou | 30E 24.80' N 88E 38.09' W | GCRL32341 | 21 |
| 5/26/99 | Sioux Bayou | 30E 24.45' N 88E 37.07' W | GCRL32342 | 2 |
| 5/26/99 | Pascagoula River | 30E 14.74' N 88E 53.06' W | GCRL32343 | 22 |
| 5/26/99 | Pascagoula River | 30E 22.56' N 88E 36.31' W | GCRL32344 | 12 |
| 5/27/99 | Pascagoula River | 30E 22.21' N 88E 36.50' W | GCRL32345 | 3 |
| 5/27/99 | Pascagoula River | 30E 21.65' N 88E 35.94' W | GCRL32346 | 4 |
| 5/28/99 | Lowery Bayou | 30E 23.72' N 88E 35.89' W | GCRL32347 | 26 |
| 5/28/99 | Lowery Bayou | 30E 23.07' N 88E 35.22' W | GCRL32776 | 4 |
| 5/28/99 | Lowery Bayou | 30E 23.35' N 88E 35.39' W | GCRL32348 | 4 |
| 7/12/99 | Snake Bayou | 30E 24.12' N 88E 35.21' W | GCRL32349 | 28 |
| 7/12/99 | Snake Bayou | 30E 24.50' N 88E 35.33' W | GCRL32350 | 33 |
| 7/12/99 | Snake Bayou | 30E 24.85' N 88E 35.58' W | GCRL32351 | 14 |
| 7/13/99 | Coleson Bayou | 30E 25.58' N 88E 35.31' W | GCRL32352 | 28 |
| 7/13/99 | Coleson Bayou | 30E 25.12' N 88E 35.17' W | GCRL32353 | 5 |
| 7/13/99 | Coleson Bayou | 30E 25.36' N 88E 34.98' W | GCRL32354 | 6 |
| 7/26/99 | Southwest Bayou | 30E 22.66' N 88E 24.96' W | | 0 |
| 7/26/99 | Southwest Bayou | 30E 22.91' N 88E 24.96' W | GCRL32355 | 1 |
| 7/26/99 | Clay Bayou | 30E 23.07' N 88E 24.71' W | | 0 |
| 7/27/99 | Middle Bayou | 30E 23.64' N 88E 24.96' W | GCRL32356 | 3 |
| 7/27/99 | Middle Bayou | 30E 23.54' N 88E 24.74' W | GCRL32357 | 2 |
| 7/27/99 | Middle Bayou | 30E 23.28' N 88E 24.49' W | GCRL32358 | 1 |
| 7/28/99 | Bayou Heron | 30E 24.70' N 88E 24.19' W | GCRL32359 | 5 |
| 7/28/99 | Bayou Heron | 30E 23.82' N 88E 24.20' W | GCRL32360 | 3 |
| 7/28/99 | Bayou Heron | 30E 23.30' N 88E 23.84' W | | 0 |

**TABLE 1. Continued.**

| Date | Bayou | Latitude/Longitude | Museum # | # Specimens |
|------|-------|--------------------|----------|-------------|
| 8/11/99 | Bayou Cumbest | 30E 23.35' N88E 26.69' W | | 0 |
| 8/11/99 | Bayou Cumbest | 30E 23.11' N88E 26.59' W | | 0 |
| 8/11/99 | Bayou Cumbest | 30E 22.43' N88E 26.64' W | GCRL32361 | 2 |
| 9/06/99 | Bayou off Bangs Bayou | 30E 21.84' N88E 26.87' W | GCRL32362 | 1 |
| 9/06/99 | North Bayou | 30E 22.28' N88E 27.39' W | | 0 |
| 9/06/99 | Bayou off Bangs lake | 30E 22.10' N88E 28.41' W | GCRL32363 | 4 |
| 9/07/99 | Crooked Bayou | 30E 22.03' N88E 25.94' W | | 0 |
| 9/07/99 | Crooked Bayou | 30E 22.42' N88E 25.41' W | | 0 |
| 9/07/99 | Crooked Bayou | 30E 22.01' N88E 24.98' W | | 0 |
| 9/08/99 | Krebs Lake | 30E 23.28' N88E 33.69' W | GCRL32364 | 6 |
| 9/08/99 | Lake Catch-em-all | 30E 23.89' N88E 33.92' W | GCRL32365 | 2 |
| 9/08/99 | McInnis Bayou | 30E 24.71' N88E 34.55' W | GCRL32366 | 6 |
| 8/06/99 | Tidal creek off Bayou La Fourche | 30E 25.56' N88E 23.67' W | GCRL32367 | 1 |
| 8/06/99 | Tidal creek off Bayou La Fourche | 30E 23.78' N88E 23.54' W | GCRL32368 | 2 |
| 8/06/99 | Tidal creek off Bayou La Fourche | 30E 23.54' N88E 23.52' W | GCRL32369 | 1 |
| 8/07/99 | Bayou La Fourche | 30E 23.90' N88E 22.27' W | | 0 |
| 8/07/99 | Bayou La Fourche | 30E 23.89' N88E 22.90' W | GCRL32370 | 3 |
| 8/07/99 | Bayou La Fourche | 30E 24.22' N88E 22.66' W | GCRL32791 | 2 |
| 8/20/99 | Little River | 30E 23.86' N88E 17.70' W | | 0 |
| 8/20/99 | Little River | 30E 23.43' N88E 17.57' W | GCRL32372 | 1 |
| 8/20/99 | Little River | 30E 23.34' N88E 17.04' W | GCRL32373 | 2 |
| 8/21/99 | Portersville Bay | 30E 22.90' N88E 15.71' W | | 0 |
| 8/21/99 | Bayou Sullivan | 30E 23.09' N88E 14.09' W | | 0 |
| 8/23/99 | Negro Bayou | 30E 23.11' N88E 14.01' W | GCRL32374 | 1 |
| 8/23/99 | Fowl River West | 30E 23.11' N88E 14.18' W | GCRL32375 | 2 |
| 8/23/99 | Fowl River West | 30E 23.11' N88E 14.10' W | GCRL32376 | 8 |
| 8/24/99 | Fowl River East | 30E 24.95' N88E 08.43' W | GCRL32377 | 6 |
| 8/24/99 | Fowl River East | 30E 26.32' N88E 08.39' W | | 0 |
| 8/24/99 | Fowl River East | 30E 26.79' N88E 07.72' W | | 0 |
| 8/25/99 | Bayou Caddy | 30E 24.29' N88E 20.33' W | GCRL32378 | 2 |
| 8/25/99 | Grand Bayou | 30E 24.01' N88E 19.73' W | | 0 |
| 8/25/99 | Bulls Bay Bayou | 30E 24.17' N88E 21.72' W | | 0 |
| 1/25/01 | Simmons Bayou | 30E 22.25' N88E 45.08' W | MMNS26826 | 2 |
| 1/25/01 | Simmons Bayou | 30E 22.35' N88E 44.58' W | MMNS26827 | 5 |
| 1/25/01 | Simmons Bayou | 30E 22.35' N88E 44.58' W | MMNS26828 | 1 |

## TABLE 2

Listing of physical-chemical data by study. Top values in each cell are total range of conditions whereas the bottom values are those where fish were actually collected. na = not available. * = temperature data for these collections was influenced by an aquaculture facility discharge canal which was much warmer than ambient upstream water.

| Study | Number of specimens | Salinity (‰) | Temperature (°C) | DO (mg/L) | Turbidity (NTU) | Depth (m) |
|---|---|---|---|---|---|---|
| 1985–1986 | 19 | 0.0–4.0 | 10.0–32.0 | 1.0–9.8 | 1.6–10.8 | 0.2–0.80 |
| | 375 | 0.0–0.0 | 10.0–34.0 | 4.1–9.6 | 1.1–14.4 | 0.1–0.70 |
| | 49 | 2.4–8.5 | 8.0–31.5 | 5.1–9.5 | 2.0–36.0 | 0.3–0.75 |
| 1996 | 138 | 0.9–1.7 | 25.1–33.7 | 3.0–7.4 | 4.9–68.6 | 0.2–1.50 |
| 1999 | MS:248 | 0.0–7.5 | 25.6–32.1 | 2.1–7.8 | 0.5–17.4 | 0.2–0.70 |
| | | 2.4–7.5 | | 2.7–7.8 | 3.2–17.4 | |
| | AL:31 | 6.4–5.8 | 28.9–32.0 | 2.7–7.4 | 1.9–21.8 | 0.3–0.50 |
| | | 12.8–5.4 | | 2.8–5.8 | 4.5–21.3 | |
| 2001 | 8 | 0.2–6.0 | 10.2–26.2* | 7.4–11.5 | na | 0.3–0.60 |
| | | 2.4–6.0 | 10.2–17.3* | 8.2–11.5 | na | 0.3–0.65 |

salinity and water temperature were low and depth was about 0.5 m. Higher water depth were related to sampling on high tides with bag seines. However, sampling occurred only in spring and summer in 1996 and 1999, thus water temperature only ranged from 25.1 to 33.7°C. We cannot predict the occurrence of *F. jenkinsi* at temperatures below this range. Patterns of abundance among salinity zones in collections obtained by bag seines or Breder traps were similar for zones below 12‰ but more *F. jenkinsi* were collected in Breder traps than bag seines in salinities > 12‰ (Figure 3A). Although Breder traps were set at high tide (regardless of time of day), water depth between gear types was similar (Figure 3B). The patterns of *F. jenkinsi* abundance relative to water temperature are biased between the two gear types (Figure 3C), with all Breder trap collections occurring only between late spring and late summer. Examination of all bag seine and Breder trap data, however, indicated *F. jenkinsi* were mainly collected when salinities were ≤ 12‰ (90.7% of total collected), depth were near 0.5 m, and water temperatures ranged between 20.0 and 32.0°C. Salt marsh collection sites which appeared appropriate in terms of dominant vegetation, depth and water temperature but that did not produce *F. jenkinsi,* had a mean salinity of 17.0‰ (2.5–26.4‰).

A combined total of 40 species were collected in the 1996 and 1999 collections. In the 1996 collections (Breder traps and bag seines), *F. jenkinsi* was second in abundance behind *Fundulus grandis* whereas in the 1999 collections (Breder traps only), it was third behind *F. grandis* and *Poecilia latipinna.*

## DISCUSSION

*Fundulus jenkinsi* is generally considered rare and has a "special" status in many states in the northern Gulf of Mexico. The Mississippi Museum of Natural History, Wildlife Heritage Program considers this species important by placing it on their list of Priority Research Species. Gilbert and Relyea (1992) also state that this species is restricted to the extreme western Florida panhandle and is considered "threatened" in that area. Our results not only indicate that *F. jenkinsi* is more abundant than previously suggested in the central part of its range but that salinity is an important environmental factor influencing its CPUE and distribution. Habitats with salinities < 12‰ produced more *F. jenkinsi* in our region; indeed, salt marsh sites which appeared to be appropriate but did not produce *F. jenkinsi* had a mean salinity of 17.0‰ (0–27.5‰; 52.2% of those sites were ≤ 12‰). In fact, the majority of published studies support our salinity results.

In addition to being the center of its distribution range, the north-central Gulf of Mexico has produced the majority of recorded specimens (Gilbert and Relyea 1992) compared to those recorded to the west and east of our region. For example, in Texas Simpson and Gunter (1956) reported that 2 *F. jenkinsi* were collected between 1–9.9‰, 10 between 10.0–19.9‰, and 12
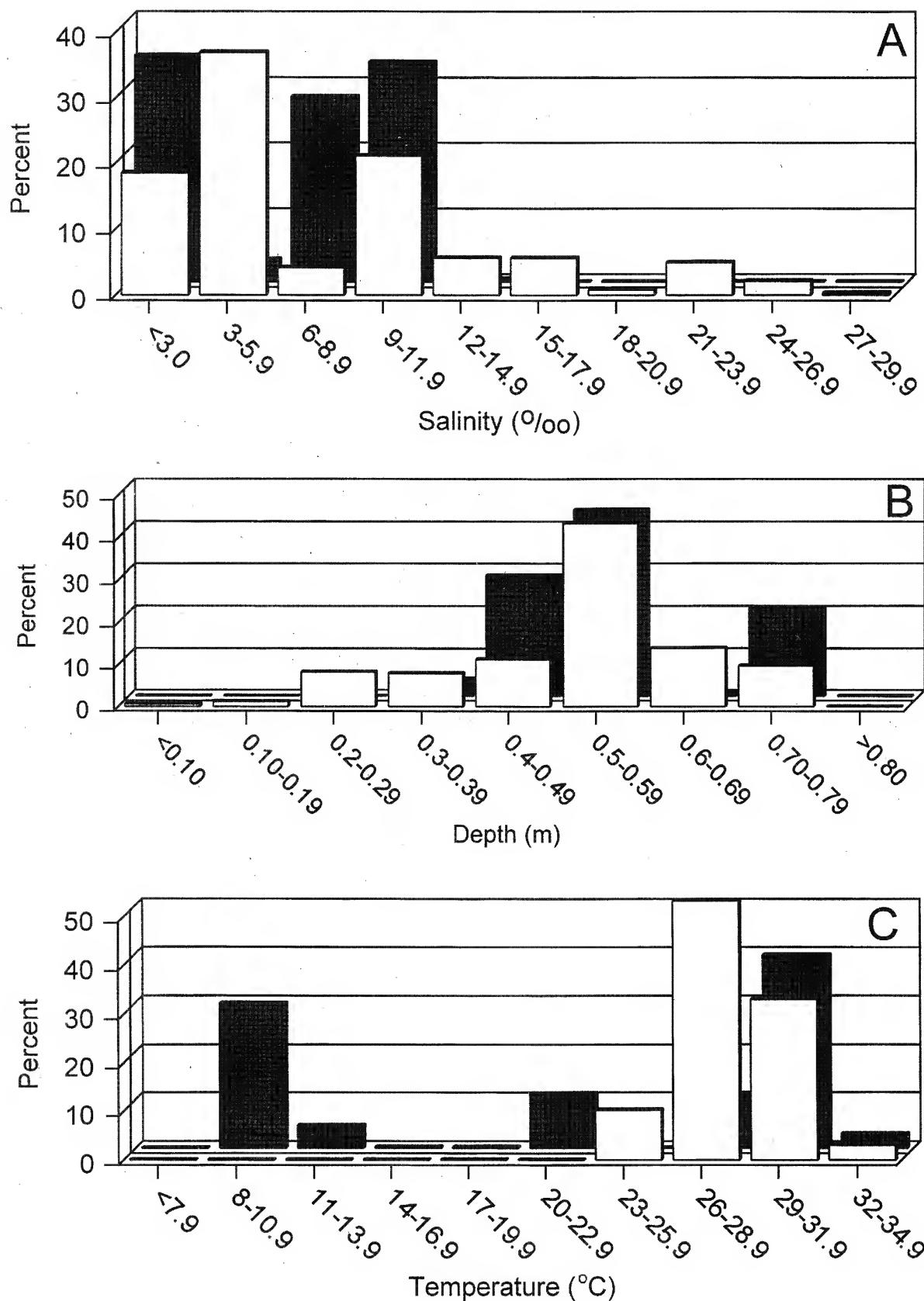
**Figure 3. Plot of percent of the total number (*n* = 868) of *F. jenkinsi* in Breder traps (white histograms) and seines (black histograms) collected versus salinity (A), water depth (B), and water temperature (C) at the site.**

between 20.0–29.9‰. In west-central Louisiana, Neill and Turner (1987) noted 7 specimens in Boston Bayou South of the Vermilion Bay system where salinity was 8‰. In a series of papers from the Terrebonne-Timbalier estuarine system, Rozas (1992a, 1992b) and Rozas and Reed (1993) documented this species in oligo- to mesohaline *Spartina* salt marshes in small numbers using lift nets or small trawls. In contrast, Peterson and Turner (1994) in the same marsh system indicated that using flume nets *F. jenkinsi* was the ninth most abundant species (*n* = 102) and was a marsh resident. In Mississippi, this species has been infrequently collected and when collections are made this species is typically not very abundant compared to other fundulids. Caldwell (1966) collected *F. jenkinsi* in an artesian well pool from an abandoned fish hatchery near Bay St. Louis and Cook (1959) noted that this species has been collected in Simmons Bayou off Biloxi Bay. Indeed, our collections in 1996 and 2001 confirmed the presence of this species in Simmons Bayou. Peterson (1987) and Peterson and Ross (1991) reported 443 *F. jenkinsi* were collected with a 6.1 m bag seine over 13 months in 1985–1986 from tidal freshwater to mesohaline sections of Old Fort Bayou, Mississippi. Recently, Suttkus et al. (1999) reported collecting 393 specimens between October 1950 and 1985 from 8 sites in St Louis Bay, Mississippi. Other Mississippi collections in a number of coastal drainages did not produce *F. jenkinsi* (Fowler 1945; Beckham 1977), however. In coastal Alabama, Swingle and Bland (1974) recorded 2 specimens from freshwater and 175 specimens taken between 2–25‰. Boschung (1992) lists this species from a number of coastal Alabama bayous. Bailey et al. (1954) collected 80 individuals from near the confluence of the Escambia River and Escambia Bay where surface salinity was 4.5‰. Thus, based on published data and the results of this study, it is clear this fundulid prefers oligohaline to mesohaline salinities (*sensu* Cowardin et al. 1979) associated with *Spartina* or *Juncus* salt marshes in the north-central Gulf of Mexico and is less abundant both east and west of this geographic location.

The ability to assess distribution and CPUE of rare species that are linked to tidal dynamics requires sampling with appropriate gear. For example, our earlier work on use of different sampling gears to collect this species (Fulling et al. 1999) illustrated that using a 3 m bag seine, *F. jenkinsi* was not collected very often during high and low tide seining efforts compared to collection at the same sites with Breder traps in our geographic region. Additionally, we documented the first records of *F. jenkinsi* (*n* = 50) in the Pascagoula River from one of its tributaries, Mary Walker Bayou, in 1996 using Breder traps (Fulling et al. 1999), a result which we speculate may not have occurred if we had used only bag seines. Finally, our data suggest that this species is more widely distributed and abundant along the Mississippi and Alabama coasts than previously suggested (Smith-Vaniz 1968, Ross and Brenneman 1991, Boschung 1992). Indeed, Mettee et al. (1996) does not list *F. jenkinsi* in their book detailing fishes of Alabama and the Mobile Basin. We feel the use of sampling gear designed to collect resident marsh fishes is imperative as noted in Fulling et al. (1999). Additionally, variation in annual rainfall and the subsequent extent and patchiness of low salinity salt marsh area from year to year may influence year class strength of this fundulid. These may explain why this species appears rare or absent in most fish studies of the northern Gulf of Mexico (Caldwell 1966, Hastings 1987, Hastings et al. 1987, Cashner et al. 1994).

Given the direct connection between coastal wetlands and fisheries species, and that coastal populations have increased by 40 million people since 1960 (Waste 1996), the Federal register (14 July 1997, Vol. 62(134)) placed *F. jenkinsi* on the list of Candidate Species. The recent, but extensive, development in coastal Mississippi of the dock-side gaming industry has added further concern about the status of *F. jenkinsi* in these north-central coastal wetlands because they have produced the majority of recorded specimens (Gilbert and Relyea 1992). Meyer-Arendt et al. (1998) indicated that over 13% (8,500 acres) of the saltmarsh in coastal Mississippi had been lost between the 1950's and 1992, with 40% of that acreage being converted directly from marsh to developed land. Because of its distribution in naturally variable and highly desired low-salinity bayou habitat, this small fundulid will continue to be impacted due to development.

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# Gulf and Caribbean Research

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## Using a Modified Purse Seine to Collect and Monitor Estuarine Fishes

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## Recommended Citation

# USING A MODIFIED PURSE SEINE TO COLLECT AND MONITOR ESTUARINE FISHES

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*Abstract* We developed a modified purse seine to sample shallow water estuarine habitats and evaluated the efficacy of using this gear as a tool for monitoring estuarine fish populations in Tampa Bay, Florida. The purse seine (183-m long, 5.2 m deep and 50-mm stretch mesh nylon throughout) was easily deployed and retrieved by a 7 m flat-bottomed, bow-driven boat with a hydraulic wench and aluminum pursing davit. Retention rates of pinfish (*Lagodon rhomboides*) marked and released into 35 net sets averaged 49% (range 9–100%). Retention rates were not significantly influenced by sets over vegetated and unvegetated bottom types, various water depths from 1–3.3m and sets with and without bycatch. We then used the modified purse seine to sample fishes at 550 randomly selected sites in Tampa Bay from January 1997 to December 1998. Sampled habitats ranged from 1.0 to 3.3 m deep and included seagrass beds and non-vegetated sand or mud bottoms. Benthic, demersal, and pelagic fishes were captured, indicating the purse seine effectively sampled the entire water column. A wide size range of fishes was collected including pre-recruitment sizes of several economically important species. The ability of purse seines to fish independent of adjacent shorelines allowed us to sample nearshore waters that included large expanses of seagrass meadow.

## INTRODUCTION

Purse seines have been used for centuries to capture pelagic fishes in subsistence fisheries throughout the world (Ben-Yami 1994). During the 20th century, purse seines revolutionized several important commercial fisheries in the United States, including Pacific tuna and Atlantic menhaden fisheries (McNeely 1961, June 1972, Schaaf and Huntsman 1972). In the Gulf of Mexico, purse seines are used in the Gulf menhaden fishery, which reports an average of 560,500 metric tons landed per year (Smith et al. 2002), and the Florida baitfish fishery, which supports a multimillion dollar industry in Florida (Pierce and Mahmoudi 2001).

Though widely used in commercial fisheries, purse seines have been used by scientists conducting fisheries-independent studies only when traditional sampling gears were inadequate for the researchers' needs. Hunter et al. (1966) used a 'miniature' purse seine to collect juvenile pelagic fishes that congregated beneath floating material at sea. Levi (1981) developed a two-boat purse seine to collect menhaden for mark and recapture experiments. Both authors found the purse seine to be suitable as a collection gear and commented on its potential in fisheries science. Despite these uses and Kjelson and Colby's (1977) specific suggestion that purse seines be developed for monitoring estuarine fish populations, our study in Tampa Bay, Florida, documents the first known use of a purse seine in a multispecies fisheries-independent study with a random-sampling design.

Florida's Fisheries-Independent Monitoring (FIM) program monitors the relative abundance of fish stocks in seven estuaries around the state including Tampa Bay. Gear used by the FIM program includes small-mesh seines to sample juvenile fishes recruiting to shallow waters and trawls designed to capture these juveniles in the deeper parts of the estuary (Nelson 1998). Large haul seines are used to collect large-juvenile and adult fishes and have proven to be effective for this purpose (Kupschus and Tremain 2001); however, this gear is restricted to use along shoreline habitats. Our interest was to expand our sampling of large fishes (> 75 mm) to include areas away from the shoreline in Tampa Bay. The ability of purse seines to sample the entire water column, and to fish areas away from the shoreline, made it a promising gear for this purpose.

Tampa Bay is a shallow estuary with a modal depth of 3 m and a shallow shelf along the periphery that varies in width from 500 m to 1,200 m (Lewis and Estevez 1988). Much of this nearshore estuarine environment includes expansive seagrass meadows. Seagrasses are known to influence the abundance and diversity of ichthyofauna in Florida estuaries and are well documented as critical habitat for many fish species (Stoner 1983, Comp and Seaman 1985, Sogard et al. 1989), but historically have been under-sampled by our program. The purpose of this study was to: 1) design a purse seine and vessel suitable for fishing estuarine waters to 3.3 m deep; and 2) evaluate the efficacy of using this gear through gear retention experiments and random sampling as part of the FIM program's objectives to monitor

large-juvenile and adult fish populations in Tampa Bay, Florida.

## MATERIALS AND METHODS

### Gear description

The 183 m purse seine used in this study was a scaled-down version of commercial purse seines used in Florida's baitfish industry. The body (wing) of the net was constructed of 50 mm stretch mesh knotless #242 nylon twine and was 5.2 m deep. Football floats (0s2) were spaced every 61 cm and pipe leads were spaced every 30 cm along the body of the net. The bunt end (bag) was 16 m long x 7 m deep and constructed of 50 mm knotted #15 nylon. Floats were positioned more tightly together along the bag of the net to minimize escapement during net retrieval. Stainless steel alpine clips (10 cm long) were used for purse rings and were attached to the lead line of the net with lengths (45–63.5 cm) of 10 mm polypropylene line. Purse rings were spaced 3.1 m apart on the wing and 1.5 m apart on the bag. The purse line was a single length (250 m) of 10 mm low-stretch nylon yacht braid.

### Vessel Description

The vessel used in this study was a 7 m mullet skiff; a flat-bottomed, bow-driven boat capable of running in shallow water (< 1 m). The skiff had a large, open net-well that allowed the purse seine to be deployed quickly from the stern. We modified the mullet skiff by installing a hydraulic system and an aluminum pursing-davit (Figure 1). A 40-L hydraulic system was driven by an 8-hp engine coupled to a gear pump that created 72.5 KPa (500 psi) at 2,500 revolutions per minute. Attached to the pursing-davit were a capstan and net roller used to retrieve the net. A dual-circuit hydraulic valve was used to control the capstan and the net roller independently. The capstan was 15 cm in diameter, turned at 75 revolutions per minute and retrieved the purse line at a rate of approximately 11 m per minute. A 14 mm stainless steel rod (ring bar) held the purse rings in position, and a 45 kg tom weight kept the purse line on the bottom while the net was being pursed. The cost of net construction, purse rings, tom weight and purse line was about US$12,000 and vessel modifications including aluminum davit and hydraulic components cost an additional US$2,500.

Deployment of the purse seine was similar to that described by Ben-Yami (1994). In estuarine conditions where tidal currents affected the set, we standardized the shape of the set to an oval pattern to minimize the amount of net set across the current (Figure 2). An average set sampled ca. 2,210 m$^2$ and required 25 minutes to deploy and retrieve the gear.
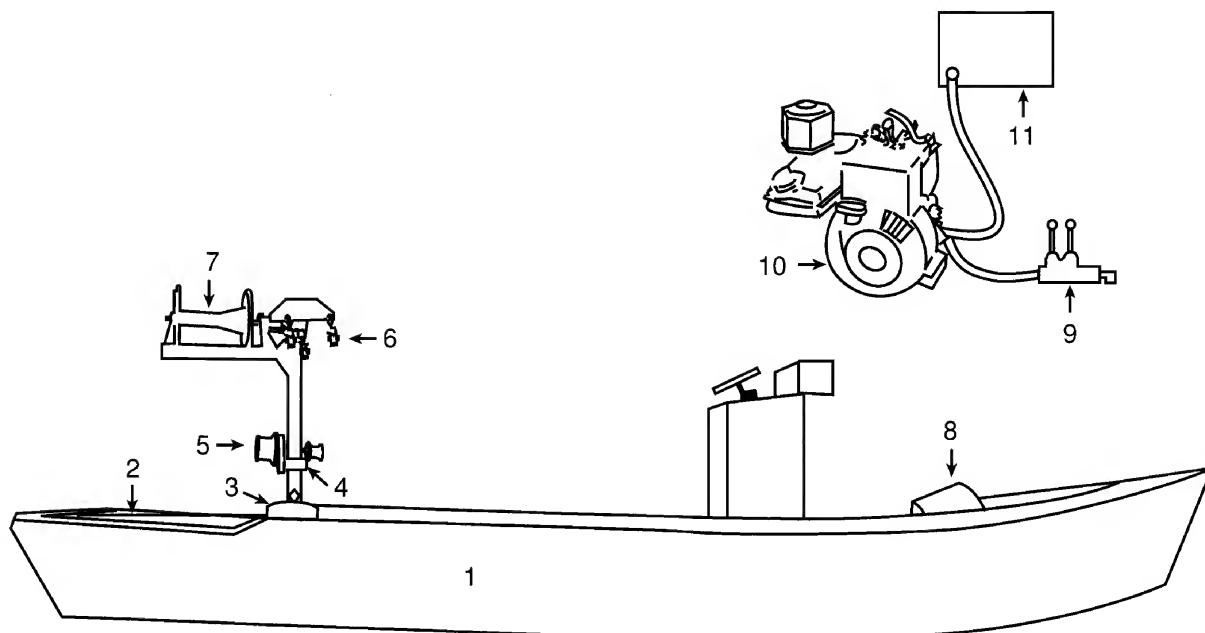


Figure 1. Mullet skiff and equipment used to convert the skiff to a purse seiner. 1 = mullet skiff, 2 = ring bar, 3 = tom weight, 4 = hydraulic motor, 5 = capstan, 6 = blocks, 7 = net roller, 8 = outboard engine, 9 = dual-circuit hydraulic valve, 10 = 8 hp gas engine w/coupled hydraulic gear pump, 11 = 40-L hydraulic tank.
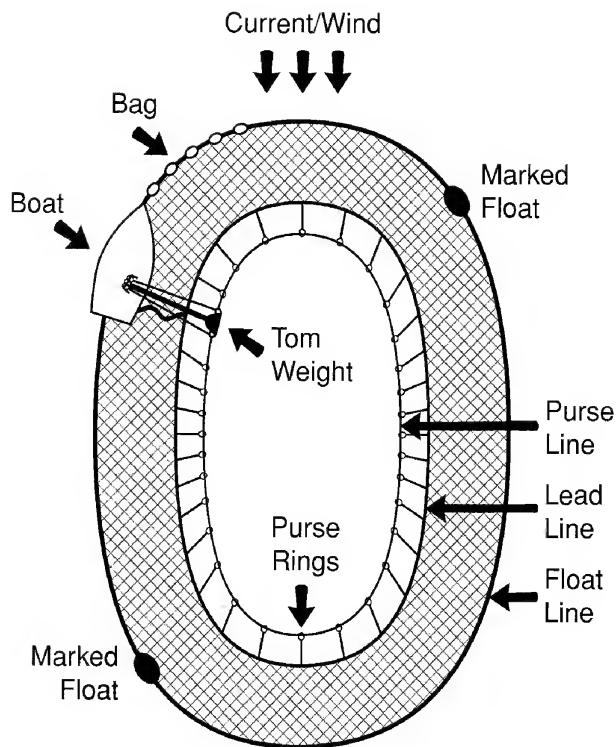
**Figure 2. Diagram of a typical 183-m purse seine set in estuarine conditions. Set is made in an oval shape and started into the current.**

## Gear Retention

We designed an experiment to estimate purse seine gear retention using mark and recapture techniques. We conducted the experiment in lower Tampa Bay in an area with expansive seagrass meadows and unvegetated sand/silt bottom. Sets were stratified by water depth (i.e., < 1.6 m or 1.6–3.3 m). Pinfish (*Lagodon rhomboides*), the most abundant species available during gear testing trials, were used for the experiment. Experimental animals were collected, measured (SL, mm), marked by clipping a portion of the anal fin, and held in the net well of a second (release) boat until approximately 60 fish were collected for an experimental set. Only pinfish in good condition and ≥ 105 mm SL and 45 mm body depth (42 mm was the inside dimension of the 50 mm stretch-mesh knotless nylon twine, as measured on a wet net using digital calipers) were used in the experiment to avoid effects of mesh selectivity on retention estimates.

Marked fish were released throughout the area encircled by the net once the wing and bag end were together and the tom weight was on the bottom. The net was then pursed and all fish collected. Captured fish were measured and checked for fin clips (marks). The number of recaptured fish was recorded for use in retention estimates.

Mean retention rate and associated variance was calculated using the ratio estimator described by Charles-Dominique (1989). We assumed that marked and unmarked fish were equally capable of escaping during the retrieval process. Retention rate estimates were subjected to normality tests (Shapiro-Wilks test: Zar 1996) which indicated a normal distribution. The Student's two-sample t-test was then used to test retention rate differences between vegetated and unvegetated bottom types, presence or absence of bycatch, quantity of bycatch (0–38 L vs > 38 L), and water depth ( < 1.6 m vs. 1.6–3.3 m).

### Random Sampling

After thoroughly field testing the modified purse seine, we incorporated it into the FIM program's Tampa Bay random-sampling design beginning in January 1997. Sampling locations were randomly selected each month from all possible sites in Tampa Bay < 3.3 m in water depth. Sampling effort was distributed evenly throughout the available sampling area in Tampa Bay. At each sample location, we recorded environmental variables such as water depth, bottom type, by-catch type and quantity, and abiotic variables (i.e., temperature (°C), salinity (‰), dissolved oxygen (mg/ml), and pH).

Captured fishes were identified in the field to the lowest practical taxon and enumerated. At least 20 randomly selected individuals of each species collected in each sample were measured to the nearest millimeter standard length (SL). Length statistics were generated for all species and density estimates calculated for species where more than 100 individuals were collected. Length-frequency histograms were plotted for four commonly collected species of economic importance. Density estimates (Number of fish/1000 m$^2$) and Shannon-Wiener diversity ($H'$) estimates were calculated for each set and their distributions tested for normality. Due to significant departures from normality, the Wilcoxon rank-sum test was used to compare density and diversity estimates between sets over vegetated and unvegetated bottom types.

### RESULTS

#### Gear Retention

A total of 2,015 pinfish were marked and used in thirty-five replicate gear-retention trials. The trial's mean retention rate was 49% and ranged from 9% to 100%, with a coefficient of variation (CV) of 45%. Retention rates were not significantly different between sets over vegetated and unvegetated bottom types or

## TABLE 1

**Mean retention rates and results of Student's two-sample t-test for variables recorded in association with experimental purse seine mark and recapture sets.**

| Variable | Level | Number of sets | Mean % Retention | Std. Dev. (diff.) | t-value (P-value) |
|---|---|---|---|---|---|
| Bottom vegetation | Seagrass | 22 | 52.7 | | 1.89 |
| | No seagrass | 13 | 37.9 | 22.33 | (0.067) |
| Water depth | Shallow (< 1.6 m) | 18 | 50.9 | | 0.98 |
| | Deep (1.6–3.3 m) | 17 | 43.2 | 23.2 | (0.334) |
| Bycatch | Presence | 19 | 45.4 | | 0.48 |
| | Absence | 16 | 49.3 | 23.4 | (0.63) |
| Bycatch quantity | Low (< 38 L) | 24 | 43.3 | | 1.50 |
| | High (> 38 L) | 11 | 55.7 | 22.8 | (0.143) |

sets in shallow (< 1.6 m) and deep water (1.6–3.3 m). Retention rates were also not affected by presence or quantity of bycatch (Table 1).

### Random Sampling

The purse seine was deployed in shallow-water (< 3.3 m) habitat types, including seagrass flats and sand and mud bottoms, throughout Tampa Bay, Florida. Most sets took place more than 100 m from an adjacent shoreline, and less than 20% of the sets occurred over seagrass (vegetated: $n = 93$, unvegetated: $n = 457$). Typically, five net sets were completed in a sampling day. Mean set time, including sample processing, was 45 minutes and varied with size of the catch.

In 550 purse seine sets, 54,082 individuals representing 84 fish species were collected, ranging in size from 25 mm to more than 1,000 mm SL (Table 2, Figure 3). The purse seine catch included both juvenile and adult fishes. Demersal ($n = 34$), pelagic ($n = 34$), and benthic species ($n = 16$) comprised 52%, 45%, and 3% of the total catch, respectively. Density and diversity estimates were significantly higher (density $P < 0.001$; diversity $P = 0.048$) in sets over vegetated bottom types (Figure 4).

The purse seine catch was dominated by pinfish, which were collected in 48% of the hauls and made up 25% of the total catch. Clupeids, including *Opisthonema oglinum* (threadfin herring), *Brevoortia* spp. (menhaden), and *Harengula jaguana* (scaled sardine), composed 25% of the total catch. Sciaenids, including *Bairdiella chrysoura* (silver perch), *Leiostomus xanthurus* (spot), *Menticirrhus americanus* (southern kingfish), *Cynoscion arenarius* (silver seatrout), and

*Cynoscion nebulosus* (spotted seatrout), composed an additional 13% of the total catch.

Many of the species ($n = 27$) collected were of economic importance, composing about 20% of the total catch (Table 2). The most abundant economically important species in the catch were *Elops saurus* (ladyfish), spot, silver seatrout, spotted seatrout, *Paralichthys albigutta* (southern flounder), and southern kingfish. Length-frequency distributions for several economically important fish species included modal sizes reflecting cohorts of pre-fishery recruits (Figure 5).

### DISCUSSION

We developed, tested, and implemented a modified purse seine for sampling estuarine fish populations in Tampa Bay, Florida. We found that the purse seine could be consistently set in a variety of estuarine habitat types and that the sample area was easily standardized and quantified. The purse seine is an active gear, and the dimensions and design of the net characterize how and where it may be fished. Our net was designed to sample the entire water column in depths of 1–3.3 m. The maximum depth fished by this type of purse seine is simply limited by the depth of the webbing used. The maximum depth for our net was selected based upon the topography of Tampa Bay (modal depth = ~ 3 m) and our desire to sample deep seagrass beds, previously under-sampled with other gear types used by our program. Seagrass beds are critical habitat for many fish species (Comp and Seaman 1985, Sogard et al. 1989, Rozas and Odum 1988).

## TABLE 2

**Species collected with a 183-m purse seine in Tampa Bay from January 1997 through December 1998 (550 sets). Species are listed by decreasing order of number of individuals collected and density estimates and frequency of occurrence (%) are provided where greater than 100 individuals were collected. Species of economic importance are indicated by '$'.**

| | Species | Individuals Collected | Density Fish/1000m² (% Occurrence) | Standard length (mm) Mean | Standard length (mm) Range |
|---|---|---|---|---|---|
| | *Lagodon rhomboides* | 13,769 | 11.33 (48.7) | 110 | 31–203 |
| | *Opisthonema oglinum* | 7,337 | 6.04 (23.6) | 144 | 74–196 |
| $ | *Elops saurus* | 5,215 | 4.29 (27.8) | 311 | 143–490 |
| | *Harengula jaguana* | 4,160 | 3.42 (27.6) | 119 | 61–209 |
| $ | *Leiostomus xanthurus* | 3,185 | 2.62 (16.5) | 137 | 93–210 |
| | *Arius felis* | 3,181 | 2.62 (48.9) | 270 | 95–506 |
| | *Bairdiella chrysoura* | 2,394 | 1.97 (16.4) | 137 | 114–185 |
| | *Brevoortia* spp. | 1,943 | 1.60 (11.5) | 198 | 104–280 |
| | *Orthopristis chrysoptera* | 1,300 | 1.07 (21.5) | 129 | 48–215 |
| | *Chaetodipterus faber* | 1,236 | 1.02 (13.6) | 112 | 45–275 |
| | *Eucinostomus gula* | 1,138 | 0.94 (22.0) | 95 | 55–135 |
| | *Rhinoptera bonasus* | 1,038 | 0.85 (29.3) | 590 | 249–970 |
| | *Dasyatis sabina* | 902 | 0.74 (43.1) | 246 | 65–590 |
| | *Chilomycterus schoepfi* | 849 | 0.70 (43.1) | 133 | 25–282 |
| | *Lactophrys quadricornis* | 829 | 0.68 (40.2) | 142 | 35–288 |
| | *Chloroscombrus chrysurus* | 795 | 0.65 (16.2) | 132 | 66–198 |
| $ | *Cynoscion arenarius* | 674 | 0.55 (11.1) | 203 | 101–324 |
| $ | *Cynoscion nebulosus* | 551 | 0.45 (23.6) | 249 | 125–545 |
| | *Bagre marinus* | 477 | 0.39 (19.3) | 315 | 119–520 |
| | *Prionotus scitulus* | 477 | 0.39 (35.5) | 139 | 53–200 |
| | *Caranx hippos* | 232 | 0.19 (7.1) | 191 | 118–354 |
| $ | *Paralichthys albigutta* | 213 | 0.17 (20.7) | 178 | 90–371 |
| $ | *Menticirrhus americanus* | 206 | 0.17 (11.5) | 205 | 143–315 |
| | *Aluterus schoepfi* | 141 | 0.12 (8.2) | 252 | 92–347 |
| | *Eucinostomus harengulus* | 135 | 0.11 (4.9) | 94 | 43–194 |
| | *Dasyatis say* | 123 | 0.10 (12.2) | 415 | 130–623 |
| $ | *Scomberomorus maculatus* | 115 | 0.10 (10.4) | 296 | 140–494 |
| | *Monacanthus hispidus* | 95 | . | 79 | 48–165 |
| | *Synodus foetens* | 88 | . | 194 | 102–270 |
| $ | *Pomatomus saltatrix* | 83 | . | 298 | 136–450 |
| | *Oligoplites saurus* | 81 | . | 167 | 62–261 |
| | *Sphoeroides nephelus* | 80 | . | 140 | 97–225 |
| | *Caranx crysos* | 71 | . | 154 | 110–218 |
| | *Trinectes maculatus* | 71 | . | 82 | 60–116 |
| | *Achirus lineatus* | 67 | . | 72 | 52–100 |
| $ | *Archosargus probatocephalus* | 56 | . | 172 | 73–430 |
| $ | *Menticirrhus saxatilis* | 56 | . | 212 | 137–290 |
| | *Rhinobatos lentiginosus* | 53 | . | 416 | 258–660 |
| | *Peprilus alepidotus* | 47 | . | 135 | 44–180 |
| $ | *Mugil gyrans* | 45 | . | 153 | 117–230 |
| | *Selene vomer* | 45 | . | 131 | 38–178 |

## Table 2 (Continued)

| Species | Individuals Collected | Density Fish/1000m² (% Occurrence) | Standard length (mm) Mean | Range |
|---|---|---|---|---|
| *Prionotus tribulus* | 36 | . | 119 | 54–186 |
| *Opsanus beta* | 36 | . | 128 | 53–227 |
| $ *Trachinotus falcatus* | 32 | . | 237 | 130–350 |
| *Diplodus holbrooki* | 31 | . | 92 | 76–122 |
| $ *Mugil cephalus* | 29 | . | 245 | 149–400 |
| $ *Lutjanus griseus* | 26 | . | 170 | 114–213 |
| $ *Haemulon plumieri* | 25 | . | 112 | 83–168 |
| *Hippocampus erectus* | 21 | . | 126 | 82–155 |
| *Nicholsina usta* | 21 | . | 144 | 120–176 |
| *Symphurus plagiusa* | 21 | . | 130 | 35–160 |
| $ *Sphyrna tiburo* | 20 | . | 503 | 294–692 |
| $ *Trachinotus carolinus* | 20 | . | 261 | 181–398 |
| *Ancylopsetta quadrocellata* | 17 | . | 166 | 74–225 |
| *Gymnura micrura* | 17 | . | 343 | 202–538 |
| *Dorosoma petenense* | 14 | . | 123 | 100–140 |
| *Echeneis naucrates* | 14 | . | 373 | 286–520 |
| *Lactophrys trigonus* | 14 | . | 91 | 36–126 |
| $ *Mycteroperca microlepis* | 12 | . | 234 | 169–330 |
| $ *Rachycentron canadum* | 12 | . | 529 | 231–820 |
| *Dasyatis americana* | 11 | . | 560 | 310–790 |
| *Decapterus punctatus* | 9 | . | 179 | 172–190 |
| *Calamus arctifrons* | 9 | . | 136 | 90–207 |
| *Diapterus plumieri* | 8 | . | 74 | 65–88 |
| $ *Centropristis striata* | 8 | . | 109 | 75–137 |
| *Hemicaranx amblyrhynchus* | 8 | . | 126 | 77–160 |
| *Lutjanus synagris* | 8 | . | 118 | 109–136 |
| *Aluterus scriptus* | 6 | . | 118 | 100–143 |
| $ *Centropomus undecimalis* | 5 | . | 532 | 248–740 |
| *Scorpeana brasiliensis* | 5 | . | 110 | 68–132 |
| $ *Menticirrhus littoralis* | 5 | . | 239 | 185–370 |
| *Ogcocephalus radiatus* | 5 | . | 154 | 86–243 |
| *Lepisosteus osseus* | 4 | . | 828 | 650–1,050 |
| $ *Sciaenops ocellatus* | 4 | . | 452 | 378–538 |
| $ *Mugil curema* | 3 | . | 177 | 148–233 |
| *Caranx ruber* | 2 | . | 157 | 147–166 |
| *Diplectrum formosum* | 2 | . | 153 | – |
| *Etropus crossotus* | 2 | . | 101 | 100–102 |
| $ *Micropogonias undulatus* | 2 | . | 129 | 123–134 |
| *Astroscopus y-graecum* | 1 | . | 101 | – |
| *Aetobatus narinari* | 1 | . | 525 | – |
| *Hippocampus zosterae* | 1 | . | 121 | – |
| *Hyporhamphus unifaciatus* | 1 | . | 159 | – |
| *Lepisosteus platyrhincus* | 1 | . | 1,005 | – |
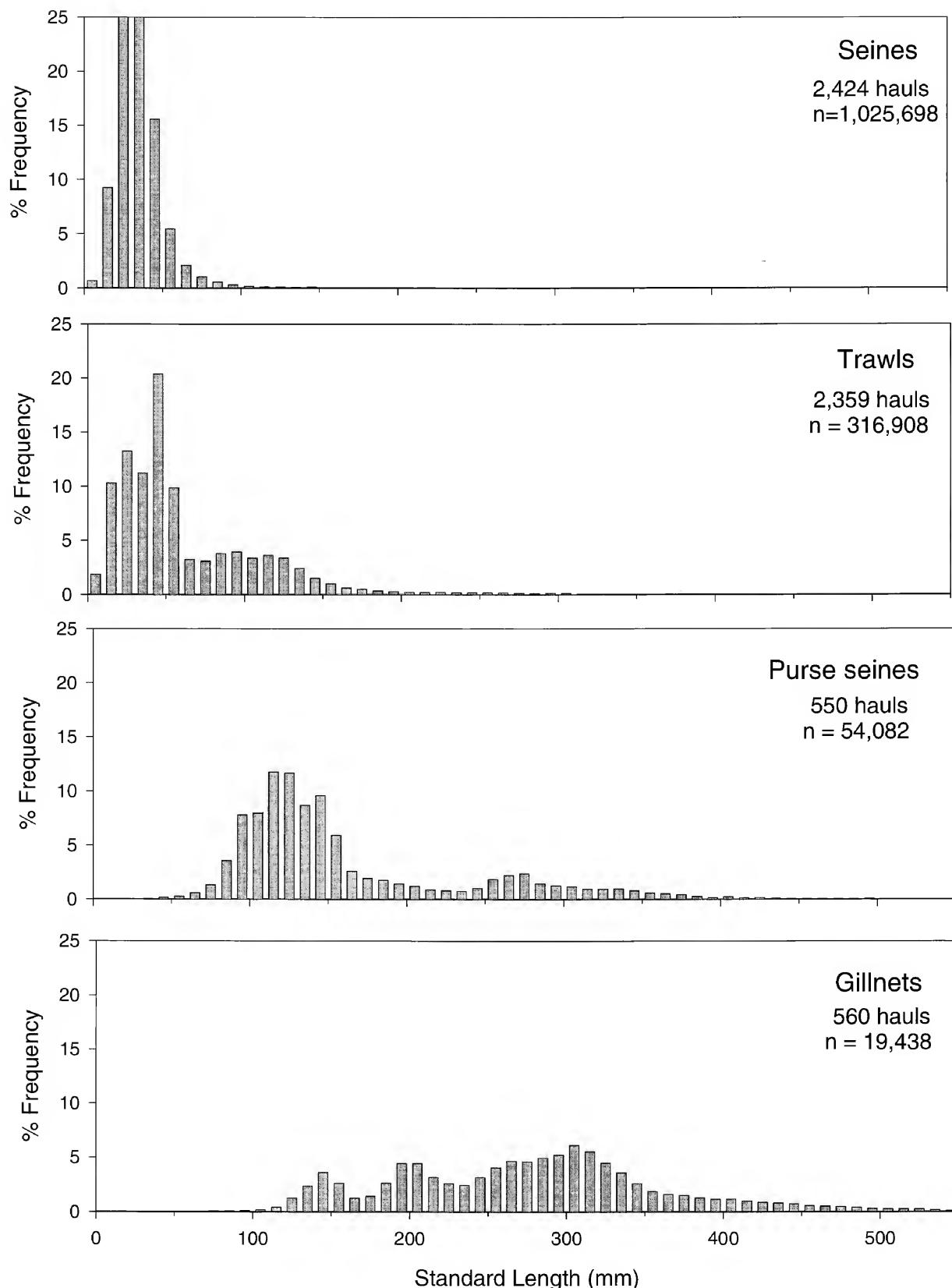
Figure 3. Overall length-frequency distributions (SL mm, all species combined) of fish captured in small seines (1989–1997 seasonal), trawls (1989–1997 seasonal), purse seines (1997–1998, current study), and gillnets (1989–1995 seasonal, night-time) collections conducted by the FIM program in Tampa Bay, Florida.

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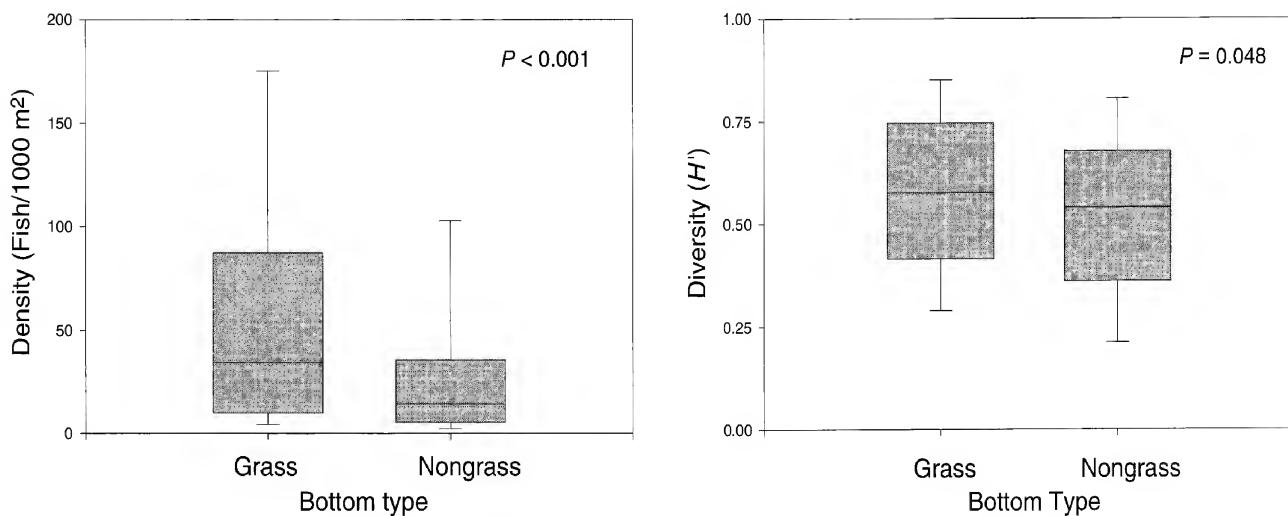
**Figure 4.** Box and whisker plots of Density (Fish/1000m²) and Shannon-Wiener diversity estimates (*H'*) in Tampa Bay purse seine sets over vegetated (*n* = 93) and unvegetated (*n* = 457) bottom types in Tampa Bay 1997–1998. Median estimates (horizontal line) and 25th and 75th quartiles (box) are shown with 5th and 95th percentiles as the whiskers.

The purse seine provided valuable data on the diverse fish communities inhabiting nearshore environments of Tampa Bay. We collected a variety of fish species and a wide size range using the purse seine. The design of the gear allowed us to collect benthic (e.g., southern flounder, *Dasyatis sabina* [atlantic stingray]), demersal (e.g., pinfish, silver perch), and pelagic (e.g., menhaden, scaled sardine) fish species. Pre-recruitment size classes for several species of recreational or commercial importance were represented. Collections of economically important species (e.g., ladyfish, spot, spotted seatrout, silver seatrout), provided us with life-history data later used to develop age-length keys for ongoing fisheries management purposes (Table 2).

The FIM program's previous attempts to characterize large-juvenile and adult fish populations associated with Tampa Bay's nearshore estuarine environments included the use of 6.1 m otter trawls and multi-panel gillnets (2" to 6" stretched mesh). These types of gear were decidedly unproductive for this purpose (McMichael 1995). Trawls sampled only near the bottom and rarely captured fishes greater than 75 mm in SL (Figures 3 and 5), while gillnet effectiveness relied on nighttime sampling and extended soak-times (ca. 1.5 hours not including time for retrieval and sample work up) that reduced the number of samples that could be collected in a given sampling trip. Further, gillnet selectivity and their use as a passive gear, limits their effectiveness for multi-species surveys (Rozas and Minello 1997).

Our aim in developing the purse seine was to complement the catch of seines and trawls by collecting

fish greater than 75 mm SL. Length frequency distributions showed that purse seine samples contained the highest proportion of fishes between 100 mm and 200 mm SL (Figure 3). This size class of fishes was dominated by pinfish, small coastal pelagics (e.g., scaled sardine, threadfin herring), and other species that are important trophic links between primary producers and a variety of piscivorous fish species (Seaman and Collins 1983, Sogard et al. 1989, Pierce and Mahmoudi 2001).

Raw catch data can be inaccurate without estimates of gear efficiency (Kjelson and Colby 1977). Since either escapement or avoidance can affect efficiency of a gear, retention estimates are an important part of understanding the overall effectiveness of a fishing gear. Avoidance estimates were beyond the scope of our study; however, estimating the rate at which a gear type retains fish can be used as an upper estimate of the efficiency of a gear (Charles-Dominique 1989). Variability in retention rates in our study was consistent across several comparison groups (bottom type, water depth, and bycatch) suggesting purse seine efficiency was stable over a variety of estuarine conditions.

Purse seine retention rates and variability in our study were similar to many other types of gear that are routinely used in fisheries science. Kjelson and Johnson (1974) reported retention rates ranging from 10% to 60% for a large offshore pull-through seine, and Charles-Dominique (1989) estimated retention rates for their purse seine at between 10% and 79% using techniques similar to those employed in our study. Kjelson and Colby (1977) reported gear-efficiency estimates (which

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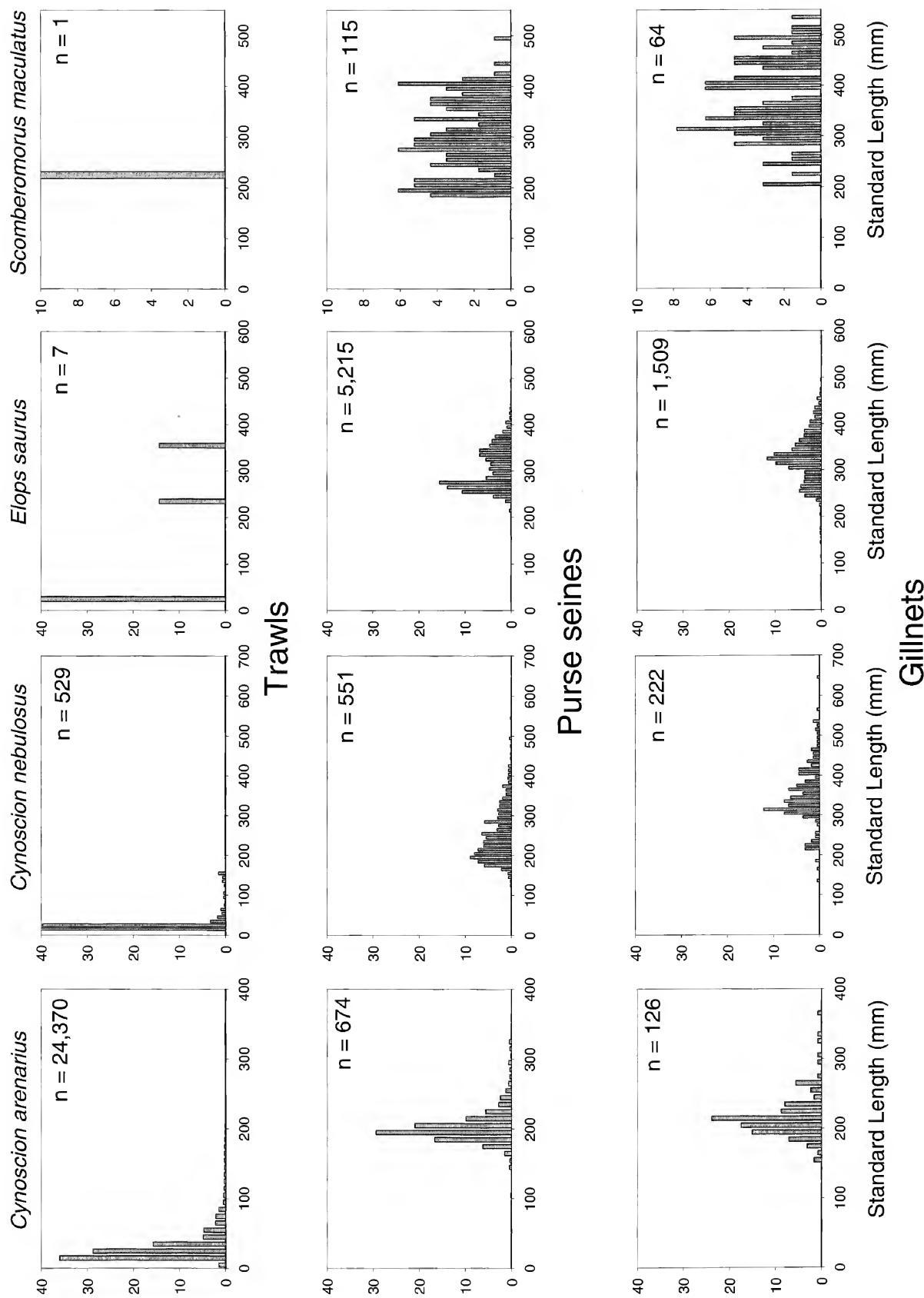
**Figure 5. Length-frequency distributions (SL mm) of four species of economic importance collected using trawls (1989–1997 seasonal), purse seines (1997–1998, current study), and gillnets (1989–1995 seasonal, nighttime) by the FIM program in Tampa Bay, Florida.**

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included avoidance estimates) for a variety of sampling gears (i.e., plankton net, beam trawl, portable drop net, haul seines, and otter trawls) that ranged from 5% to 80%, and similar variability in gear-efficiency estimates have been reported by other authors as well (Weinstein and Davis 1980, Parsley et al. 1989). Rozas and Minello (1997) recommended enclosure gears, including purse seines, for sampling shallow estuarine waters due to their generally higher catch efficiency and ease in quantification of the sample area; however, purse seines were not recommended for use over seagrass. In contrast, our purse seine performed reliably well over vegetated bottom types and provided important information on fish species utilizing these critical habitats.

In conclusion, the use of a purse seine has enabled our program to obtain quantitative information on large juveniles and adults of benthic, demersal, and pelagic fishes inhabiting estuarine waters of Tampa Bay, Florida. This gear allowed our program to adequately sample a variety of estuarine habitats in which previous attempts using trawls and gillnets had been less successful. Gear-efficiency estimates for our purse seine based on retention-rate experiments were comparable with those of other types of sampling gear typically used in fisheries science, and the purse seine was durable enough for standard field use. The purse seine had limitations, as do other gear types. It was susceptible to strong tidal currents and winds, which caused the lead line to roll, twisting the purse line and rings into the webbing. Further, the gear could not be fished properly in areas with obstructions or hard bottom, that snagged the net or purse line. Finally, the initial costs associated with building a purse seine, and the vessel to work the gear, were considerable (about US$15,000).

Future studies will concentrate on the versatility of the purse seine as a sampling tool in other Florida estuaries and comparisons with the catch of large haul seines used along shoreline habitats, providing more information on the benefit of this gear type as an ecological fish-monitoring tool.

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